ABSTRACT

Background: Posterior shoulder tightness (PST) has been implicated in the etiology of numerous shoulder disorders. Although reliable and valid measures have been described for the non-operative population one does not exist for the post-operative population.

Study Design: Blinded repeated measures design.

Purpose: Investigate the intrarater reliability, minimal detectable change at the 90% confidence interval (MDC$_{90}$) and construct validity of an inclinometric measurement designed to quantify PST in the post-operative population.

Methods: One investigator performed PST measurements on the operative shoulder of 23 participants. Passive internal and external rotation measurements were performed for the validity component of the investigation.

Results: Intrarater reliability using an intraclass correlation coefficient (ICC) model 3, $k$ was good (ICC = 0.79). The MDC$_{90}$ indicated that a change of greater than or equal to 8 degrees would be required to be 90% certain that a change in the measurement would not be the result of inter-trial variability or measurement error. Construct validity was supported by a statistically significant relationship between PST and internal rotation $r = 0.54$ and by a relationship between PST and external rotation $r = 0.30$ which was not statistically significant.

Conclusion: The sidelying procedure described in this investigation appears to be a reliable and valid means for quantifying PST in the post-operative population. Moreover, the use of inclinometry provides an absolute angle of tightness that may be used for intersubject comparison, documenting change, and to determine reference values.

Level of Evidence: Therapy, level 2b

Key Words: capsule, flexibility, mobility, range of motion

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INTRODUCTION

Epidemiological data suggests that up to sixty-seven percent of the general population will experience shoulder pain at some point in their lifetime. The shoulder complex ranks third among regions treated by physical therapists in outpatient clinics and has been reported to be a primary location of injury or pain among individuals who participate in weight-training, baseball, football and wrestling. A survey of American Shoulder and Elbow Surgeons Society members revealed that these surgeons performed on average greater than 300 shoulder cases annually. Although the etiology of shoulder disorders is multifactorial, specific impairments such as inadequate mobility and posterior shoulder tightness (PST) have been associated with common disorders such as labral tears and impingement syndrome in both the general and athletic population.

Throwing athletes, in particular have a predilection for PST owing to repetitive microtrauma at the posterior capsule during the late cocking and follow through phases of the throwing motion. It has been postulated that tensile stresses placed on the shoulder during throwing may induce hypertrophy and thickening of the posterior inferior capsule thus producing PST. Although these capsular changes have been implicated in the etiology of PST, it must be recognized that muscular restrictions may be involved as well. Reinold et al found acute decreased internal rotation among professional baseball players following pitching that were present 24 hours following practice further supporting the contribution of acute musculotendinous adaptations on internal rotation.

Although common to the overhead athlete, PST has been reported among other subgroups of the population. Tyler et al reported increased PST among individuals diagnosed with impingement syndrome when compared to controls. Ticker et al reported an association between impingement syndrome and posterior capsular thickening-shortening among patients with a history of shoulder pain undergoing arthroscopy. Additionally, an association between PST and recreational weight-training participation has been reported among asymptomatic individuals when compared to controls suggesting the potential for task specific tissue adaptations.

Furthermore, shoulder stiffness has been reported as a post-operative complication among individuals having undergone shoulder surgery. Brislin et al reported persistent shoulder stiffness as being the most common complication following arthroscopic rotator cuff repair. A recent review of the literature regarding complications associated with arthroscopic rotator cuff repair reported the incidence of persistent post-operative stiffness to range from 1.5–11.1% second only to the incidence of re-rupture. Huberty et al reported that 95.5% of patients with post-operative shoulder stiffness requiring a secondary capsular release had impaired internal rotation.

Clinical recognition of risk or pathology attributed to PST as well as changes as a result of specific treatments utilized to reduce PST requires a reliable and valid measurement technique that may be used among the heterogeneous population and that is of reasonable expense and availability. Measurement techniques for PST have been reported in the literature using both supine and sidelying procedures as well as with varying instruments including inclinometry, goniometry, and a tape measure. Essentially, the techniques described attempt to isolate glenohumeral horizontal adduction by restricting scapular movement. Tyler et al first described a sidelying technique for quantifying PST, whereby the scapula is stabilized in retraction while the humerus is passively adducted across the chest, while being maintained at 90 degrees of forward flexion and neutral rotation. The distance from the medial epicondyle to the table is recorded with larger distances implying greater PST. Good intra and interrater reliability of this technique were reported, with an intraclass correlation coefficient (ICC) of 0.92 and 0.80 respectively. Myers et al assessed the intra and interrater reliability of the sidelying technique using a linear measurement device that recorded the distance between the table and medial epicondyle and reported ICCs = 0.42-0.83 and 0.69 respectively. Myers et al assessed the intra and interrater reliability of the sidelying technique using a linear measurement device that recorded the distance between the table and medial epicondyle and reported ICCs = 0.42-0.83 and 0.69 respectively. A disadvantage of both of the aforementioned sidelying techniques is that PST is not quantified using an absolute value that can be directly compared between individuals. Other researchers have examined PST using supine measurements performed with either inclinometry or goniometry and reported good intra and interrater reliability (ICC = 0.75-0.94); however, a disadvantage of this technique is the inability to visualize a consistent start position of the scapula.
A modified sidelying measurement method, performed with the use of an inclinometer, to permit intersubject comparison has yielded good interrater reliability (ICC = 0.90).28 A recent review of the literature in regards to methods for quantifying PST indicates that current research in this area has only been performed on the asymptomatic and or non-operative population, suggesting a need for investigation of quantifying PST in the post-operative population.29 To our knowledge no previously published investigations have reported the intrarater reliability, minimal detectable change (MDC90) and construct validity of a sidelying PST measurement using inclinometry within the post-operative shoulder population.

The purpose of this study was to investigate the intrarater reliability, MDC90 and construct validity of a previously investigated sidelying inclinometric measurement technique designed to quantify PST28 within the post-operative population. Construct validity was evaluated using passive internal rotation (IR) for convergence given the direct relationship between posterior capsuloligamentous tension and IR.30-32 External rotation (ER) was used for discrimination as biomechanical studies have identified an absence of influence between PST and ER.32 The authors hypothesized that the PST measurement would have good intrarater reliability based on the nature of the testing procedures. In regards to validity, a strong positive relationship would exist between PST and IR with little or no relationship between PST and ER was hypothesized. Passive measurements of IR and ER were used to establish validity since participants had recently undergone shoulder surgery and the above-mentioned procedure for measuring PST is also performed passively.

METHODS
Participants
A convenience sample of 23 consecutive patients, 13 men and 10 women, seeking postoperative physical therapy following arthroscopic shoulder surgery between May 2011 and December 2011 were screened for eligibility in this study. The inclusion criteria consisted of patients having had arthroscopic shoulder surgery within the past two weeks preceding data collection with no surgical complications, age 18-65, and seeking treatment at Southeastern Orthopedic Physical Therapy where the primary investigator of the study is employed. Exclusion criteria consisted of patients having had total shoulder arthroplasty, hemi shoulder arthroplasty, open rotator cuff repair, shoulder fracture fixations, and those seeking an initial evaluation after two weeks from the date of the surgical procedure. Demographic data was collected from each patient including gender, age, height, weight, and handedness. The mean ± SD age, body mass index, and height for subjects was 51 ± 9.7 years, 26.67 ± 4.0 kg/m², and 173.60 ± 9.5 centimeters respectively and all 23 subjects were right hand dominant. Patients that met the inclusion criteria and agreed to be in the study were provided with and signed an informed consent form approved by the Institutional Review Board at Nova Southeastern University.

Instruments
A standard plinth and Baseline® bubble inclinometer (Fabrication Enterprises, White Plains, NY) was used for each of the measurements performed in this study. The measurements of PST were performed using a bubble inclinometer attached to a Velcro strap that was placed around the patients mid-humerus (Figure 1). A 24-inch bubble level (Johnson Level & Tool, Mequon, WI) was used to set the inclinometer to a zero point in regards to the starting position (such that the zero point was perpendicular to the plinth) before measurements were taken and after any handling of the inclinometer to ensure an accurate zero starting point.
Procedures
Prior to all measurement procedures patients performed a standard warm up that was not believed to offer a mobilization effect or affect PST. The purpose of the warm up exercises was to reduce potential soreness from the measurement positions without effecting PST. Warm up exercises consisted of 10 scapular retractions in a seated position and 10 pendulum exercises, performed with approximately 45 degrees of trunk flexion and no weight, in small clockwise circles. Following the warm-up exercises, PST was measured in the operative shoulder and repeated three times with a 10 second rest between each measurement. The patient was allowed to rest for 10 minutes. Warm-up exercises were again performed after the 10 minutes of rest and then three repeated PST measurements were again taken. This short test/re-test interval was specifically chosen given the rapid rate at which post-operative shoulder range of motion changes. Moreover, given the risk of arthrofibrosis patients are routinely treated on day one therefore measurements performed on a different day would have been invariably higher, thus compromising agreement. After the second set of PST measurements was performed, passive IR and passive ER of the operative shoulder were also measured using an inclinometer. Prior to testing, uniform verbal instruction was provided to each patient regarding the positioning of their arm and to promote relaxation. A physical therapist trained in recording data from the inclinometer recorded all measurements on single data collection sheet to ensure that the clinician was blinded to the findings. A single clinician with over four years of experience in an orthopedic shoulder setting performed all measurements.

Posterior Shoulder Tightness Measurement
The procedure for measuring PST was adapted from the protocol used by Kolber and Hanney. The inclinometer was placed around the mid-humerus of the operative arm using a Velcro strap. The patient was asked to lie on their non-operative side with their non-operative arm under their head to assume neutral head position. Their trunk was perpendicular to the plinth and both the hips and knees flexed to 45 degrees. A carpenter’s square was not used to ensure the trunk remained perpendicular to the plinth because the authors wanted to accurately simulate how this measurement would be applied in clinical practice. A bubble level was used to establish a zero starting position (such that the zero point was perpendicular to the plinth) for the inclinometer in regards to horizontal adduction. The clinician stood facing the patient at the level of their shoulders. With one hand the clinician grasped the elbow of the operative arm and passively abducted the humerus to 90 degrees while maintaining zero degrees of rotation at the humerus and approximately 90 degrees of elbow flexion. The hand used to grasp the patients elbow maintained its position while the clinicians other hand was used to grasp the patient’s scapula and position it into full adduction (retraction). This established the starting position for the measurement with the humerus abducted to 90 degrees, zero degrees of humeral rotation, approximately 90 degrees of elbow flexion, and full scapular retraction (Figure 2A). At this time the clinician provided verbal commands to the patient similar to “relax your arm as I move it towards the table” before passively moving the humerus into horizontal adduction within the transverse plane while maintaining retraction of the scapula and zero degrees of humeral rotation. The clinician ceased the movement when he felt that the humerus or scapula could no longer be stabilized or when movement stopped (Figure 2B). At this time the trained assistant recorded the measurement from the inclinometer.

Passive Internal Rotation Measurement (IR-PROM)
The procedure for measuring IR-PROM was performed with the patient in supine and the patients operative arm entirely supported by the plinth. The patients humerus was passively abducted to 90 degrees while in zero degrees of rotation, the elbow flexed to approximately 90 degrees and the wrist in neutral. Neutral horizontal positioning of the humerus was achieved in this position by placing folded towels under the operative arm until the humerus was visually in line with the acromion process. The clinician placed one hand on the operative anterior shoulder to prevent protraction of the shoulder and with the other hand grasped the posterior wrist/hand of the patient’s operative extremity. The humerus was internally rotated while in the above position until the movement ceased or the clinician felt anterior
pressure against his stabilizing hand (Figure 3). At this time the trained assistant placed the inclinometer along the distal anterior forearm and recorded the measurement. The supine method for measuring internal rotation was selected over the prone method secondary to increased pain the patient may have experienced by lying on the operative shoulder and may have potentially prevented an accurate measure of internal rotation from being obtained.

**Passive External Rotation Measurement (ER-PROM)**

The procedure for measuring ER-PROM was performed with the patient in supine with their operative arm entirely supported by the plinth. The patient's humerus was passively abducted to 90 degrees while in zero degrees of rotation, the elbow flexed to approximately 90 degrees and the wrist in neutral. Neutral horizontal positioning of the humerus was achieved in this position by placing folded towels under the operative arm until the humerus was visually in line with the acromion process. The clinician placed one hand on the operative shoulder to stabilize the shoulder complex and with the other hand grasped the posterior wrist/hand of the patient's operative extremity. The humerus was externally rotated while in the above position until the movement ceased (Figure 4). At this time the trained
Data Analysis
Collected data was transferred to the Macintosh version of PASW Statistics Version 18.0 for analysis. Descriptive data including mean measurement angles with standard deviations (SD) were calculated for each series of measurements. The intrasession reliability of PST was determined by the ICC model 3, k. The mean value of each series of measurements was used for the analysis. Model 3, k was used for the intrarater analysis to determine if this particular instrument can be used repeatedly with confidence by the same clinician. Our interpretation of the ICC value was based on guidelines offered by Portney and Watkins, whereby a value of above 0.75 was classified as good and a value of 0.50 to 0.75 would be considered to have moderate to poor reliability. The standard error of measurement (SEM) is not affected by intersubject variability and is important for clinical utilization of a measurement procedure; therefore it was reported in conjunction with the ICC’s using the formula: \( \text{SEM} = \text{SD} \sqrt{1-r} \). The MDC was calculated for the intrarater measurements using the formula: \( \text{MDC}_{90} = 1.65 \times \text{SEM} \times \sqrt{2} \) to determine the magnitude of change that would exceed the threshold of measurement error at the 90% confidence level. MDC values were rounded to the nearest degree to reflect the smallest unit of measurement on the inclinometer.

Pearson product-moment coefficient of correlation (r) using a significance level of \( p = 0.01 \) was used for the analysis for the construct validity component of the investigation. This was used to determine if a relationship existed between PST and IR as well as PST and ER. An a priori power analysis indicated that a sample size of 22 would be needed to obtain 80% power when using an estimated \( r = 0.50 \) with \( \alpha = 0.05 \).

RESULTS
Mean angular measurements of PST for the intrarater reliability analysis with SD, ICC (95% CI), SEM, and MDC were presented in Table 1. The data indicates good intrarater reliability for PST (ICC = 0.79). The MDC for the intrarater analysis indicated that a change equal to or greater than 8° would be required to be 90% certain that the change is not due to intra-trial variability or measurement error.

Convergent validity was supported by a statistically significant moderate correlation between PST and internal rotation (r = 0.54) with \( p = .008 \). Discriminant validity was supported given there was no

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**Table 1. Intrarater Reliability Analysis: Posterior Shoulder Tightness Measurement.**

<table>
<thead>
<tr>
<th>Shoulder Test</th>
<th>Measurement A Mean angle (°)(SD)</th>
<th>Measurement B Mean angle (°)(SD)</th>
<th>ICC 3,k (95% CI)</th>
<th>SEM°</th>
<th>MDC° 90</th>
</tr>
</thead>
<tbody>
<tr>
<td>PST</td>
<td>22.04(7.51)</td>
<td>23.93(9.35)</td>
<td>0.79(0.51-0.91)</td>
<td>3</td>
<td>8</td>
</tr>
</tbody>
</table>

Abbreviations: SD, standard deviation; ICC, intraclass correlation coefficient; CI, confidence interval; SEM, standard error of measurement; MDC, Minimum detectable change at the 90% confidence level; PST, posterior shoulder tightness.
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statistically significant correlation between the PST measurement and external rotation ($r = 0.30$) with $p = .166$ indicating little or no relationship. Table 2 presents the PST, IR and ER measurements (mean, SD and ranges) that were obtained.

### Table 2. Measurement Angles used for Construct Validity Analysis.

<table>
<thead>
<tr>
<th>Shoulder Test</th>
<th>Mean angle° (SD)</th>
<th>Range°</th>
<th>Minimum°</th>
<th>Maximum°</th>
</tr>
</thead>
<tbody>
<tr>
<td>PST</td>
<td>23.93(9.35)</td>
<td>37</td>
<td>8</td>
<td>45</td>
</tr>
<tr>
<td>Internal Rotation</td>
<td>21.65(12.28)</td>
<td>56</td>
<td>4</td>
<td>60</td>
</tr>
<tr>
<td>External Rotation</td>
<td>48.73(13.05)</td>
<td>43</td>
<td>60</td>
<td>68</td>
</tr>
</tbody>
</table>

Abbreviations: SD, standard deviation; PST, posterior shoulder tightness

DISCUSSION

This investigation sought to determine the intrarater reliability, MDC, and construct validity of a measurement procedure designed to quantify PST within the post-operative population. Although the posterior capsule and ligamentous structures have been implicated as primary contributors to PST\(^{17,30,32}\) it can not be stated with absolute certainty that they are the only source of PST, therefore, clinicians must appreciate the potential contribution of contractile tissue.\(^{15}\)

The term PST collectively encompasses the posterior capsule, posterioinferior glenohumeral ligament as well as the tendinous portion of the posterior rotator cuff and posterior deltoid musculature.\(^{15,17,30,32,37}\) Evidence for contractile tissue contribution may be gathered from the study by Hung et al\(^{15}\), where it was reported that muscle stiffness (change in passive tension per unit change in length) increased in the posterior deltoids, teres minor, and infraspinatus when internally rotating the shoulder of patients with limited mobility, whereas muscle stiffness was reduced during external rotation. PST within the post-operative population may also be attributed to inflammation and or pre-operative tightness in the above-mentioned tissues.

Regardless of the soft tissues involved, a reliable and valid measurement technique is necessary for clinicians and researchers to recognize and quantify PST in the post-operative population. Clinical measurements isolating PST have been described in the literature;\(^{11,23-25,27}\) however, there is no consensus as to the best method.\(^{29}\) A procedure that allows the examiner to consistently maintain scapular positioning independent of body morphology while providing an absolute measurement value would be a clinically useful test.

The inclinometric measurement procedure described and examined in this investigation provided optimal positioning for identifying PST and was developed based on in vivo and in vitro investigations of tissue tension.\(^{30-32}\) Moreover, the investigated procedure provides an absolute value that may be used to document change, be useful for intersubject comparison, and can be performed by a single clinician without assistance.

Although the sidelying measurement procedure has been previously described, this investigation is the first to report the intrarater reliability, and MDC values of this method using inclinometry within the post-operative shoulder population. Previous researchers have described alternate procedures for quantifying PST in a non-operative population with fair to good reliability; however, there is disagreement on what constitutes the optimal position and measurement instrument for assessment.\(^{29}\) There is, however, a consensus that an optimal technique for quantifying PST requires isolation of true glenohumeral horizontal adduction independent of scapular protraction. Thus, optimal techniques should allow the examiner to maintain scapular retraction throughout the measurement and provide an accurate start position of retraction. Laudner et al\(^{23}\) used a supine method for quantifying PST and reported good intrarater and interrater reliability, ICC = 0.93 and 0.91 respectively using digital inclinometry in asymptomatic participants. While the reliability values were good and the authors describe a clear reproducible methodology the supine position used may not permit a consistent start position of the scapula.
for all participants given varied body morphology. If the scapula is not in full retraction the testers might underestimate PST. Moreover, the aforementioned study was performed on an asymptomatic population and the results cannot be carried over into a symptomatic cohort. Using the SEM value reported from the aforementioned study an MDC$_{90}$ of 4 degrees was calculated. Lastly, digital inclinometry is costly, thus clinicians may not have this instrument at their disposal for routine use.

The sidelying method for quantifying PST has previously been investigated by Tyler et al$^{25}$ with good inter-rater reliability, ICC = 0.80. Advantages of the sidelying technique include a reproducible method of scapular stabilization, which isolates PST and provides a consistent, objectifiable start position. A measurement of the distance between the medial epicondyle and the plinth is thought to quantify PST; however, a disadvantage of this measurement method is that it does not produce a value that could be used for comparison between individuals or to establish normative values due to the varying anthropometric characteristics between individuals. The procedures described in this paper are similar to the methods originally described by Tyler et al$^{25}$ with the exception that an inclinometer was used in this investigation for angle measurements as compared to linear measurements. Inclinometry allowed the authors of the current study to obtain an absolute value for the angle of the humerus, which can be used for intersubject comparison. The intrarater reliability of the sidelying procedure described in the aforementioned investigation was good (ICC = 0.79) but as is the case with all the aforementioned investigations, it cannot be generalized to the post-operative population. The authors of the current investigation chose to not measure PST in supine, as it is difficult to identify a consistent start position of the scapula. Moreover, the authors found it difficult to maintain a fully retracted scapular position during the measurement.

While reproducibility is imperative for any measurement, validity must be established in order to be certain that a measurement provides accurate information for clinical decision-making.$^{33}$ Construct validity may be evaluated by determining how well a measurement relates to other tests of the same and different constructs. PST and IR are thought to measure the same construct,$^{30,32}$ therefore these measurements would be expected to correlate highly or demonstrate convergence. Convergence alone is not a sufficient criterion to determine construct validity. It is also necessary to show that a construct may be differentiated from another construct, thus demonstrating the ability to be discriminant.$^{33}$ Discriminant validity indicates that different results or poor correlations would be expected from measurements that assess a different construct or characteristic.$^{33}$ ER should not be markedly affected by tension in the posterior capsuloligamentous or contractile tissues, thus a positive correlation would not be expected when compared to measurements of PST.$^{15,32}$

Conflicting evidence in regards to the validation of PST measures stated above can be seen in the recent study by Borstad and Dashottar$^{38}$ which attempted to quantify strain on posterior shoulder tissues using 5 cadaveric shoulders (fresh and fresh-frozen). The authors claim that the literature to date does not establish construct validity for current PST measurements. This study examined the strain on the posterior glenohumeral joint capsule with different testing positions, one being horizontal adduction. The positions that produced the greatest strain on the posterior glenohumeral joint capsule were the 60 degrees flexion and 40 degrees flexion positions, with the cross-body abduction test position not strongly affected by changes in posterior capsule contracture. There are however limitations to any cadaveric study in regards to the applicability of the results in a clinical setting. One of the largest limitations of the Borstad and Dashottar$^{38}$ study is in regards to the portion of the capsule that was thermally altered to best mimic a posterior capsule contracture being very broad, when the portion of the capsule most commonly involved in pitchers as well as clinically observed in degenerative shoulder cases (by the primary author) is the inferior glenohumeral ligament.$^{39}$ The authors also did not position the scapula in retraction during testing which is different than the horizontal adduction methods used to measure PST in the literature.$^{25,28,40-43}$ Moreover, the mean age of the shoulders examined was 80.9 years which is considerably older than the average age (43.5) for which patients present to outpatient clinics.$^{3}$

The choice of shoulder motions for the validity component of the current investigation was based on
IR was utilized for assessment of construct validity as osteokinematic impairments of IR at the glenohumeral joint have been associated with PST.\textsuperscript{8,12,14,15,24,25,30,31} Gerber et al\textsuperscript{30} performed surgical shortening of the posterior capsule and reported a significant reduction in internal rotation as a result confirming the association between posterior capsular tension and IR. Harryman et al\textsuperscript{31} noted a loss of shoulder flexion, horizontal adduction, and internal rotation following in vitro tightening of the posterior capsule, similar to the results of Gerber et al\textsuperscript{30} and Tyler et al\textsuperscript{8,9} identified an association between PST and internal rotation loss using clinical measurements among subjects with impingement syndrome. Branch et al\textsuperscript{32} investigated the effect of capsular tension on shoulder rotation in vitro. The study results from Branch et al\textsuperscript{32} suggest a direct relationship between IR and tension in the posterior capsuloligamentous tissues, whereas a similar relationship was not found with ER.

The results of the current study’s validity analysis suggest a statistically significant relationship between PST and IR. The mean angle of IR and PST rounded to the nearest degree was 22° and 24° respectively with a statistically significant moderate correlation ($p = .01$) $r = 0.54$. Conversely, there was no correlation between ER and PST ($r = 0.30$). These results are consistent with previous studies that documented a positive association between PST and decreased internal rotation.\textsuperscript{8,10,15,17,24,25,28,30,32,37} Tyler et al\textsuperscript{25} reported a good correlation between PST and IR using the sidelying PST measurement method among baseball pitchers and reported $r = -0.61$. An inverse correlation was reported based upon their use of a linear measurement whereas a loss of internal rotation correlated with a greater distance measured from the medial epicondyle to the plinth. Laudner et al\textsuperscript{23} reported a good correlation between IR and PST ($r = 0.72$) among baseball pitchers. Lin and Yang\textsuperscript{24} compared PST to both IR and ER in a symptomatic cohort and reported a good relationship for IR ($r = 0.69$), whereas ER had little or no relationship ($r = 0.25$). Hung et al\textsuperscript{15} measured muscle stiffness using a myotonometer, in response to IR and ER among participants with clinically reduced ROM and identified increased stiffness (change in passive tension per unit change in length) of the posterior musculature in response to IR lending support to the possible contribution of contractile tissue to PST.

Kolber and Hanney\textsuperscript{28} were the first to report MDC scores for measurements used to quantify PST with a value of MDC$_{90} = 9$ degrees within an asymptomatic population. The MDC$_{90}$ values reported in this investigation indicate that a change greater than or equal to 8° is required over treatment sessions or in research trials to be 90% certain that the change is not due to subject variability or measurement error. This MDC value may be a reflection of the population chosen for this investigation. Patients having recently undergone shoulder surgery may experience increased pain, muscle guarding, and a general fear of shoulder mobility during passive shoulder motion. Subsequent measurements may lessen these effects and allow for a greater range of motion. The MDC as reported in this investigation is the smallest amount of change that can be considered above the threshold of error,\textsuperscript{33} however, one must not make the assumption that this change has reached the threshold of clinically meaningful improvement. When interpreting change scores it should be recognized that the MDC is not the same as the minimum clinically important difference (MCID).\textsuperscript{33} The MCID is the amount of change that is clinically meaningful and is typically associated with an external criterion that indicates when meaningful change has occurred.\textsuperscript{33} The MCID was not calculated in this investigation, thus it is uncertain as to the degree of change that would be considered clinically meaningful.

Limitations
When considering the results of this study one must recognize potential limitations. This study used only post-operative participants, thus the results may not correlate with a non-operative cohort. Our age range was 32 to 64, thus future investigations are warranted on populations of a different age range if the results are to be generalized to the population. This study only investigated intrarater reliability and requires further research to investigate interrater reliability of this particular method. Lastly, one must be cautious in their interpretation of the MDC values reported in this investigation, as they are not indicative of clinically meaningful change. Future research is warranted to further investigate PST.
within the post-operative population to study open shoulder procedures, compare different techniques used to quantifying PST, determine interrater reliability of certain techniques, and continue to investigate the construct validity among proposed measures of PST.

CONCLUSION

Various procedures and instruments have been described in the literature for quantifying PST, thus it is difficult to state that the method described and investigated in this paper is superior to others and may be a potential limitation to this study. This investigation presents a reproducible and valid measurement protocol for quantifying PST in the post-operative population using an inclinometer. The clinical utility of such a procedure is high, due to low cost examination tools. The inclinometric procedure outlined in this investigation had a reliability coefficient of 0.79 which is the threshold recommended for tests to be useful in making clinical decisions and is a suitable alternative to linear measurements as it allows for intersubject comparison. Clinicians and researchers should consider the MDC values presented (8°) when interpreting change values during subsequent measurement sessions to be certain that the change is not due to intertrial variability or measurement error.

REFERENCES


ABSTRACT

**Background:** The shoulder, particularly the glenohumeral joint with its predominant reliance upon soft tissues for stability is prone to injury among the cricketers who bowl regularly. These shoulder injuries are more common in spin bowlers than fast bowlers. A decreased internal rotational difference and increased external rotational difference exist when comparing the dominant shoulder with non-dominant shoulder between overarm cricketers and non-throwing wicket keepers.

**Purpose:** To compare the glenohumeral internal and external rotation range of motion differences between fast bowlers and spin bowlers.

**Methods:** A cross-sectional design was utilized for this study. Thirty-five fast bowlers and 31 spin bowlers from an elite group were recruited based on the selection criteria. Glenohumeral passive internal and external rotational differences between dominant and non-dominant shoulders were measured using a standardized mechanical inclinometer.

**Results:** Independent t-tests revealed a statistically significant difference for external rotational difference \( p = 0.005 \) between fast and spin bowlers and no such difference for internal rotational difference \( p = 0.549 \) between them at 0.05 level.

**Conclusion:** External rotational difference is significantly different between fast bowlers and spin bowlers but not internal rotational difference.

**Level of Evidence:** Level 4

**Key words:** External rotational difference, glenohumeral internal rotational deficit, glenohumeral joint, internal rotational difference.

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INTRODUCTION

In the sport of cricket, bowlers can be categorized as fast bowlers and spin bowlers. All bowlers propel a 5.5 oz ball towards a batsman or his wickets, but a spin bowler imparts rotation to the cricket ball, which makes the ball deviate from its original direction of flight when it hits the ground. The spin bowler achieves this by rapid flexion of the fingers around one side of the ball, called “finger spin” or by rapid movements of the wrist as he or she releases the ball, called “wrist spin.”

Spin bowling contrasts with fast bowling when bowlers try to beat the batsmen by combinations of speed of delivery and deviations of the ball during flight, usually achieved by keeping the stitched seam of the cricket ball vertical and pointing towards the batsmen. Deviations may occur before the ball bounces, called “swing” or after the ball bounces, called “cut.”

During the overhead throwing motion the shoulder complex functions as a regulator of the forces generated by the legs and trunk. It is this regulating function as well as the high velocities that accompany the throwing motion that place large forces and torques on the glenohumeral joint (GHJ). These forces as well as the frequent repetition of the overhead throwing action produce severe stresses on the muscles, bones, and joints of the upper extremity. Overhead throwing athletes have been found to have greater internal/external rotation strength ratios in their dominant arm when compared to their non-dominant arm. This finding shows that the overhead throwing action places large amounts of stress on the shoulder which causes alterations of muscle strength patterns. During bowling in cricket, the internal shoulder rotators are involved in the acceleration phase of the arm through concentric contractions, while the external rotators are involved during the deceleration phase.

Repetitive pitching at high velocities over time leads to chronic adaptations of soft and osseous tissues that comprise the GHJ. These anatomic adaptations likely lead to differences in range of motion (ROM) when shoulders are compared bilaterally and when overhead-throwing athletes are compared with non-overhead-throwing athletes. Although ROM changes may be adaptive, some changes in ROM are associated with pain, decreased performance

and shoulder injuries. Researchers have theorized that throwers experience an acute decrease in internal rotation (IR); however, these authors reported comparisons between throwing and nonthrowing shoulders, between throwers and nonthrowers, or among throwers of different ages. In other previous studies that have examined changes in overhead-throwing athlete’s ROM, investigators stated that external rotation (ER) was increased and IR was decreased. When IR decreases beyond the gain in ER, the condition is called Glenohumeral Internal Rotation Deficit (GIRD). Burkhart et al proposed that GIRD may be associated with injury and, therefore, suggested that clinicians assess rotational ROM of the GHJ in competitive throwers.

A significantly greater reduction of glenohumeral IR and increase in glenohumeral ER have been reported in professional tennis players with shoulder pain, when compared to those without pain. The mechanism for this adaptation has been attributed to their repetitive overhead activity which causes stretching of the anterior capsule and tightening of the posterior capsuloligamentous/muscular complex. These soft tissue adaptations may allow anterosuperior migration of the humeral head, accounting for the development of subacromial impingement and shoulder pain. In contrast to soft tissue adaptation, increased ER and decreased IR of dominant GHJ has also been attributed to bone remodeling of the humeral neck to a retroverted orientation, which may be a protective mechanism in order to reduce the risk of shoulder injury. Total shoulder ROM, elevation, and rotational motion, especially IR decrease with physical maturation during the developmental years. The IR ROM deficit may be a clinical condition that results in other compensatory motion alterations often identified in overhead athletes. Therefore, overhead athletes should be monitored for motion changes throughout their competitive seasons.

The England and Wales Cricket Board reported that 5.5% of all injuries among the First-Class County Cricketers, during the 2001 and 2002 seasons affected the shoulder and similar findings were reported in South Africa (5.2%) and among the first-class Australian teams (7%). Australian injury surveillance
data encompassing the years 1995–2001, demonstrates that shoulder injury prevalence among batters was 0.3%, fast bowlers 0.9%, and spin bowlers as 1.1%.26 Among the 113 bowlers from English Cricket Club centers fast bowlers had a greater incidence of low back pain and knee pain compared to the spin bowlers in January 1998.2 Shoulder injuries were more common in fast bowlers with a front-on action than the bowlers with a side-on or semi front-on action and shoulder injuries were reported more among the wrist spinners than finger spinners.27 Shoulder injuries were more common in fast bowlers with a front-on action than the bowlers with a side-on or semi front-on action and shoulder injuries were reported more among the wrist spinners than finger spinners. Gregory et al speculated that this action of IR during spin bowling may predispose one to impingement and injury.2 It was documented that the presence of possible dysfunction in the shoulder rotators, combined with a front-on bowling action and external rotation hypermobility are possible predisposing factors for chronic shoulder injuries in cricket fast bowlers.27

Decreased GHJ IR may be a risk factor for shoulder injuries when related to ER ROM and arm dominance in cricketers.28 Giles and Musa reported that among the cricketers there is an increased internal rotational difference (IRD) value, indicating a greater loss of dominant to non-dominant GHJ internal rotation, and an association with a gradual onset of non-specific (GONS) shoulder pain.29 Ellenbecker et al found no significant difference in active ER ROM between dominant and non-dominant arms for both males and females, but there was a significant reduction in active IR ROM of the GHJ of the dominant to non-dominant sides has been well documented in a variety of unilateral overhead sports including volleyball, tennis, and baseball.6,7,23,31,32 It is common to measure GHJ rotational range of motion differences no significant differences were found in IRD or external rotation difference (ERD) between overarm cricketers and wicket keepers.29 The authors are not aware of any investigations comparing the glenohumeral IRD and ERD between spin bowlers and fast bowlers. It could be anticipated that spin bowlers and fast bowlers who regularly bowl overarm would have differences in glenohumeral IRD and ERD as their bowling action differs. Therefore, the purpose of this study was to examine the Glenohumeral IRD and ERD between dominant and non-dominant arms of elite cricketers, as well as to compare these measures between fast bowlers and spin bowlers.

**METHODS**

Sixty-six male elite cricketers; 35 fast bowlers with a mean (SD) age of 17.97 (1.94) years and 31 spin bowlers with a mean (SD) age of 18.48 (3.68) years were recruited from five cricket academies. The participants with a history of shoulder or upper arm pain during a 48-hour period prior to shoulder measurement, any previous upper limb fractures and surgeries, previous shoulder injuries, those suffering from any other neurological disorders, and those regularly participating in other overhead sports other than cricket were excluded from the study. This study was approved by the ethical and scientific review committee of the institution. The participants were clearly instructed about the study before obtaining written consent. Measurements were taken during on-season training sessions between June and July of 2010. Cricketers’ demographic details were collected using a questionnaire. The questionnaire was designed to collect data related to the upper limb demands of cricket, including arm dominance for bowling, and bowling type. Information was also collected related to bowling practice sessions per year, month, week and day; number of overs bowled during a practice session and match; and additional overhead sporting activities that subjects participated in. Details of subjects’ previous upper limb injuries were also collected. Isolated, passive ROM (PROM) of IR and ER were measured for dominant and non-dominant GHJs of all participants using a mechanical inclinometer with established excellent intra- and inter-rater reliability.33
PROCEDURE
Before measurements were performed, participants were allowed to perform a 5-minute warm-up program of active shoulder circumduction in clockwise and counterclockwise directions in order to reduce the risk of shoulder injury. During measurements, the participants were asked to lie supine with legs straight, neutral cervical rotation and 90° shoulder abduction, approximating the late cocking phase of the throwing position. The examiner passively rotated the GHJ to end range on two consecutive occasions prior to measuring to familiarize the participant with the movement. Movement was isolated to the GHJ during IR by maintaining pressure on the coracoid process, clavicle and posterior spine of the scapula, while palpating the head of the humerus. End range was the point at which anterior humeral head translation was initiated. The same examiner performed all measurements. The inclinometer was placed on the volar aspect of the distal forearm near wrist for measuring ER and was placed on the dorsal aspect of the distal forearm near wrist to measure IR. The examiner was blinded to the inclinometer reading and cricketer's arm dominance. After measuring IR and ER of both the upper limbs, difference in IR and ER between dominant and non-dominant limbs were calculated and recorded as IRD and ERD.

RESULTS
Data analysis was performed using the statistical software SPSS 16 (Chicago, IL). Descriptive analysis was done for all the basic characteristics of the participants including age, height, weight, hand dominance, and other sport specific characteristics like maximum level of game participation, experience, warm-up session for shoulder, cool-down session for shoulder, and shoulder specific exercises (Table 1). The descriptive statistics for the variables related to cricket practice sessions per year, month, week, and day are presented in Table 2. Table 3 displays the descriptive statistics for the variables, number of overs bowled during a practice session and match. Mean and standard deviation of ER and IR PROM of left and right GHJs of right handed fast and spin bowlers and left handed fast and spin bowlers were calculated separately (Table 4). Mean (SD) of IRD (in degrees) for fast bowlers and spin bowlers were 11.58 (+/-10.70) and 12.90 (+/-6.21) respectively and of ERD for fast bowlers and spin bowlers are 15.23 (+/-9.36) and 23.46 (+/-13.38) respectively.

Pearson correlation coefficient was used to examine correlations between IRD and ERD and age (r = -0.120 and r = -0.013), years of experience (r = 0.093 and r = 0.059), number of overs bowled during a practice session (r = -0.102 and r = -0.097) and match (r = 0.358 and r = -0.105) and none of the variables was significantly correlated with IRD and ERD at 0.05 level in fast bowlers (Table 5). Similarly in spin bowlers also no significant correlation was obtained for IRD and ERD with age (r = 0.083 and r = 0.142), years of experience (r = -0.171 and r = 0.123), number of overs bowled during a practice session (r = -0.158 and r = 0.231) and match (r = 0.040 and r = -0.159) at 0.05 level (Table 5).

The comparison of mean IR PROM and ER PROM of dominant and non-dominant sides of fast and spin bowlers revealed a statistically significant difference only for right handed fast bowlers in both ER PROM (p = 0.014) and IR PROM (p = 0.013) and right handed spin bowlers in both ER PROM (p < 0.0001) and IR PROM (p = 0.048), whereas left handed fast and spin bowlers did not show a statistically significant difference in both ER PROM and IR PROM at 0.05 level as tested by an independent t-test. The IRD and ERD values were compared between the fast bowlers and spin bowlers by using an independent t-test. A statistically significant difference was found in ERD (p = 0.005) between the fast bowlers and spin bowlers, whereas no significant difference was found for IRD (p = 0.549) between groups at 0.05 level (Table 6).

DISCUSSION
The results of this study indicate that spin bowlers and fast bowlers who bowl regularly have decreased GHJ IR and increased ER ROM in dominant shoulders compared to non-dominant shoulders. Similar results have been reported in other overhead athletes. The significant differences observed only for right handed fast bowlers (n = 31) and spin bowlers (n = 28) in both ER PROM and IR PROM between their dominant and non-dominant GHJs may be because only a few left handed fast bowlers (n = 4) and spin bowlers (n = 3) participated in this study.
These GHJ rotational changes may be attributed to repeated overhead or throwing activity causing capsuloligamentous and muscular micro-trauma, with particular reference to stretching of the anterior capsule and contracture of the posterior–inferior capsule.\(^{13,21,22}\) This mechanism of soft tissue adaptation is supported by Hsu et al, who stretched the posterior glenohumeral joint capsule of cadaveric shoulders and demonstrate increased internal rotation,\(^{36}\) and by Burkhart and colleagues, who reported that, in their experience, internal rotation could be increased with posterior capsule stretches.\(^{3}\) Similarly, McClure et al found a clinically significant improvement in IR ROM following the cross-body stretch compared to that of the sleeper stretch among the asymptomatic recreational athletes.\(^{37}\) Manske

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Fast Bowlers (N=35) Mean (SD)</th>
<th>Spin Bowlers (N=31) Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>17.97 (1.94)</td>
<td>18.48 (3.68)</td>
</tr>
<tr>
<td>Height (feet inches)</td>
<td>5.7 (0.40)</td>
<td>5.55 (0.33)</td>
</tr>
<tr>
<td>Weight (kilograms)</td>
<td>62.65 (11.76)</td>
<td>63.03 (13.26)</td>
</tr>
<tr>
<td>Hand Dominance – n(%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>31 (88.6)</td>
<td>28 (90.3)</td>
</tr>
<tr>
<td>Left</td>
<td>4 (11.4)</td>
<td>3 (9.7)</td>
</tr>
<tr>
<td>Highest level of participation - n(%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>National</td>
<td>3 (8.6)</td>
<td>3 (9.7)</td>
</tr>
<tr>
<td>State</td>
<td>32 (91.4)</td>
<td>28 (90.3)</td>
</tr>
<tr>
<td>Experience (years) – n(%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 – 5</td>
<td>26 (74.3)</td>
<td>22 (71)</td>
</tr>
<tr>
<td>6 - 10</td>
<td>9 (25.7)</td>
<td>9 (29)</td>
</tr>
<tr>
<td>Warm up Session for Shoulder - n(%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>1 (2.9)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Yes</td>
<td>34 (97.1)</td>
<td>31 (100)</td>
</tr>
<tr>
<td>Cool down Session for Shoulder - n(%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>8 (22.9)</td>
<td>9 (29)</td>
</tr>
<tr>
<td>Yes</td>
<td>27 (77.1)</td>
<td>22 (71)</td>
</tr>
</tbody>
</table>

**Table 1. Description of subjects.**
et al also reported that the posterior shoulder mobility can be increased by providing cross-body stretch alone or cross-body stretch plus joint mobilization techniques in asymptomatic athletes. An alternative explanation for this altered GHJ rotation in fast bowlers and spin bowlers is osseous adaptation of humeral retroversion in response to repetitive overhead activity, with decreased IR and equivalently increased ER. The findings of this study are in agreement with Giles and Musa who examined GHJ IR and ER differences between dominant and non-dominant shoulders in cricketers who bowl and throw overarm regularly. The present study showed a mean IRD of 11.58° and 12.90° for fast and spin bowlers respectively and mean ERD of 15.23° and 23.46° for fast bowlers and spin bowlers respectively which are more than the mean IRD (-7.9°) and ERD (8.6°) obtained by Giles and Musa. These higher values may be attributed to the inclusion of bowlers alone rather than all the cricketers (throwers, fielders, wicket keepers). In the same study Giles and Musa reported that there was no significant difference between the overarm cricketers (who regularly bowl and throw) and wicket keepers in their GHJ IR and ER differences, which is partially consistent with the findings of no significant IRD between fast bowlers and spin bowlers. However, this was inconsistent with the current study finding of significant ERD between fast bowlers and spin bowlers.

Injury surveillance data collected in Australia during the year 1995-2001 indicates that shoulder injury

<table>
<thead>
<tr>
<th>Number of practice sessions</th>
<th>Fast Bowlers (N=35)</th>
<th>Spin Bowlers (N=31)</th>
<th>p value⁹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per year</td>
<td>n (%)</td>
<td>n (%)</td>
<td></td>
</tr>
<tr>
<td>1-4 months</td>
<td>2(5.7)</td>
<td>1(3.2)</td>
<td></td>
</tr>
<tr>
<td>5-8 months</td>
<td>7(20)</td>
<td>13(41.9)</td>
<td></td>
</tr>
<tr>
<td>9-12 months</td>
<td>26(74.3)</td>
<td>17(54.8)</td>
<td>0.150</td>
</tr>
<tr>
<td>Per month</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 week</td>
<td>0(0)</td>
<td>2(6.5)</td>
<td></td>
</tr>
<tr>
<td>2 weeks</td>
<td>3(8.6)</td>
<td>2(6.5)</td>
<td></td>
</tr>
<tr>
<td>3 weeks</td>
<td>12(34.3)</td>
<td>4(12.9)</td>
<td></td>
</tr>
<tr>
<td>4 weeks</td>
<td>20(57.1)</td>
<td>23(74.2)</td>
<td>0.103</td>
</tr>
<tr>
<td>Per week</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 days</td>
<td>1(2.9)</td>
<td>1(3.2)</td>
<td></td>
</tr>
<tr>
<td>3 days</td>
<td>5(14.3)</td>
<td>4(12.9)</td>
<td></td>
</tr>
<tr>
<td>4 days</td>
<td>1(2.9)</td>
<td>3(9.7)</td>
<td></td>
</tr>
<tr>
<td>5 days</td>
<td>13(37.1)</td>
<td>11(35.5)</td>
<td></td>
</tr>
<tr>
<td>6 days</td>
<td>8(22.9)</td>
<td>9(29.0)</td>
<td></td>
</tr>
<tr>
<td>7 days</td>
<td>7(20.0)</td>
<td>3(9.7)</td>
<td>0.745</td>
</tr>
<tr>
<td>Per day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-2 hours</td>
<td>16(45.7)</td>
<td>18(58.1)</td>
<td></td>
</tr>
<tr>
<td>2.5-4 hours</td>
<td>13(37.1)</td>
<td>9(29.0)</td>
<td></td>
</tr>
<tr>
<td>5-7 hours</td>
<td>6(17.1)</td>
<td>4(12.9)</td>
<td>0.605</td>
</tr>
</tbody>
</table>

⁹ p values were calculated by using chi-square test.
Table 3. *Number of overs bowled during a practice session and match.*

<table>
<thead>
<tr>
<th>Number of overs bowled</th>
<th>Fast Bowlers (N=35)</th>
<th>Spin Bowlers (N=31)</th>
<th>p value&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n (%)</td>
<td>n (%)</td>
<td></td>
</tr>
<tr>
<td><strong>During a practice session</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-5</td>
<td>4 (11.4)</td>
<td>1 (3.2)</td>
<td></td>
</tr>
<tr>
<td>6-10</td>
<td>17 (48.6)</td>
<td>19 (61.3)</td>
<td></td>
</tr>
<tr>
<td>11-15</td>
<td>12 (34.3)</td>
<td>7 (22.6)</td>
<td></td>
</tr>
<tr>
<td>16-20</td>
<td>2 (5.7)</td>
<td>4 (12.9)</td>
<td>0.300</td>
</tr>
<tr>
<td><strong>During a match</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-5</td>
<td>3 (8.6)</td>
<td>2 (6.5)</td>
<td></td>
</tr>
<tr>
<td>6-10</td>
<td>27 (77.1)</td>
<td>24 (77.4)</td>
<td></td>
</tr>
<tr>
<td>11-15</td>
<td>4 (11.4)</td>
<td>3 (9.7)</td>
<td></td>
</tr>
<tr>
<td>16-20</td>
<td>1 (2.9)</td>
<td>2 (3.4)</td>
<td>0.619</td>
</tr>
</tbody>
</table>

<sup>a</sup> *p* values were calculated by using chi-square test

Table 4. *Mean PROM of ER and IR of GHJ for right handed and left handed participants.*

<table>
<thead>
<tr>
<th>Hand Dominance</th>
<th>Fast Bowlers (N=35)</th>
<th>Spin Bowlers (N=31)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td><strong>Right handed participants</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rt.ER&lt;sup&gt;§&lt;/sup&gt;</td>
<td>144.49 (16.58)</td>
<td>150.15 (14.96)</td>
</tr>
<tr>
<td>Rt.IR&lt;sup&gt;§&lt;/sup&gt;</td>
<td>104.79 (14.97)</td>
<td>94.68 (19.20)</td>
</tr>
<tr>
<td>Lt.ER&lt;sup&gt;†&lt;/sup&gt;</td>
<td>129.56 (15.53)</td>
<td>127.27 (9.49)</td>
</tr>
<tr>
<td>Lt.IR&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>112.79 (11.64)</td>
<td>104.29 (17.92)</td>
</tr>
<tr>
<td><strong>Left handed participants</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rt.ER&lt;sup&gt;§&lt;/sup&gt;</td>
<td>136.99 (11.07)</td>
<td>146.33 (17.24)</td>
</tr>
<tr>
<td>Rt.IR&lt;sup&gt;§&lt;/sup&gt;</td>
<td>116.16 (10.16)</td>
<td>108.11 (10.86)</td>
</tr>
<tr>
<td>Lt.ER&lt;sup&gt;†&lt;/sup&gt;</td>
<td>154.83 (16.40)</td>
<td>153.55 (20.03)</td>
</tr>
<tr>
<td>Lt.IR&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>114.74 (6.10)</td>
<td>108.22 (17.81)</td>
</tr>
</tbody>
</table>

PROM: Passive range of motion; GHJ: Glenohumeral joint; <sup>§</sup> External rotation of right shoulder (in degrees); <sup>†</sup> Internal rotation of right shoulder (in degrees); <sup>‡</sup> External rotation of left shoulder (in degrees); <sup>‡</sup> Internal rotation of left shoulder (in degrees)
prevalence among pace bowlers was 0.9% and spin bowlers was 1.1%. Similarly, Gregory et al reported that 10% of fast bowlers and 16.7% of spin bowlers developed shoulder injuries. This increased prevalence of shoulder injuries among the spin bowlers may be associated with increased ERD values as was demonstrated in the findings of the current study.

Rotational motion differences between dominant and non-dominant shoulders of baseball players grew larger as the age increases. Even though the present study found a difference in IRD between fast bowlers and spin bowlers it was not statistically significant. The explanation for this failure to detect significant IRD between the groups may be because of the lower mean age (18.21 years) of the bowlers. The prior study that demonstrated a significant difference in IRD had a mean subject age of 30 years.

Kibler and colleagues found a significant correlation between increasing IRD with both increasing age and years of tennis exposure, supporting an adaptive

---

**Table 5. Correlation between IRD and ERD with other characteristics of participants.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>IRD&lt;sup&gt;†&lt;/sup&gt;</th>
<th>ERD&lt;sup&gt;‡&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fast Bowlers</td>
<td>Spin Bowlers</td>
</tr>
<tr>
<td></td>
<td>( r ) (( p ) value)</td>
<td>( r ) (( p ) value)</td>
</tr>
<tr>
<td>Age</td>
<td>-0.120 (0.494)</td>
<td>0.083 (0.659)</td>
</tr>
<tr>
<td>Years of experience</td>
<td>0.093 (0.594)</td>
<td>-0.171 (0.357)</td>
</tr>
<tr>
<td>Number of overs bowled during a practice session</td>
<td>-0.102 (0.561)</td>
<td>-0.158 (0.396)</td>
</tr>
<tr>
<td>Number of overs bowled during a match</td>
<td>0.358 (0.035)</td>
<td>0.040 (0.830)</td>
</tr>
</tbody>
</table>

<sup>†</sup> Internal rotational difference; <sup>‡</sup> External rotational difference

**Table 6. Rotational difference of GHJ between fast bowlers and spin bowlers.**

<table>
<thead>
<tr>
<th>Rotational difference (measured in degrees)</th>
<th>Fast Bowlers (N=35)</th>
<th>Spin Bowlers (N=31)</th>
<th>Mean difference (95% CI)</th>
<th>( t ) Statistic</th>
<th>( p ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRD&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>11.58 (10.70)</td>
<td>12.90 (6.21)</td>
<td>-1.32 (-5.71, 3.07)</td>
<td>-0.602</td>
<td>0.549</td>
</tr>
<tr>
<td>ERD&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>15.23 (9.36)</td>
<td>23.46 (13.38)</td>
<td>-8.23 (-13.86, -2.60)</td>
<td>-2.919</td>
<td>0.005&lt;sup&gt;‡&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

GHJ: Glenohumeral joint; <sup>†</sup> Internal rotational difference; <sup>‡</sup> External rotational difference; <sup>‡</sup> \( p \) value significant at 0.05 level
change in response to repetitive overhead activity among 39 high level tennis players. In the present study, variables like age and years of experience are correlated with ERD and IRD among the fast bowlers and spin bowlers, which showed a negative correlation of age with IRD in fast bowlers and a positive correlation of age with ERD in fast bowlers and with both IRD and ERD in spin bowlers, it also showed a negative correlation for years of experience with IRD in spin bowlers, positive correlation for years of experience with ERD in spin bowlers and with both ERD and IRD in fast bowlers. Though those variables (age and years of experience) are linearly related with IRD and ERD in fast bowlers and spin bowlers they are not significant. The possible reasons for this finding may be due to a lower mean subject age (18.21 years) and also because the cricket players are involved in several tasks like fielding, wicket keeping and batting along with bowling, which may contribute less stress to their GHJs when compared to tennis players. With these findings it is apparent that bowling action of respective types plays a major role in the changes that are present in GHJ rotational PROM in cricket bowlers rather than other variables.

LIMITATION, STRENGTH AND RECOMMENDATION

The present study did not differentiate the fast bowlers into sub-types including front-on, side-on and mixed action bowlers, or the spin bowlers into wrist spinners or finger spinners. Recording the different sub-types of bowling technique may have given further information regarding the GHJ rotational range orientation among different types of fast bowlers and spin bowlers.

To the knowledge of the authors, this is the first study to report the GHJ IRD and ERD between fast bowlers and spin bowlers. It is also the first study to report significantly higher GHJ ERD values for spin bowlers than fast bowlers. As there is lack of research regarding spin bowlers GHJ rotational range of motion differences, the current study has laid a path for future research in shoulder PROM of elite cricketers. Additionally, higher values of ERD in spin bowlers found in present study warrants further research with detailed kinematic analysis of fast bowling and spin bowling in order to determine the biomechanics of respective types of bowling and factors that may cause higher ERD values in spin bowlers.

CONCLUSION

A significant ERD difference exists between elite fast bowlers and spin bowlers, but there is no such difference in IRD between them and this difference may be due to their bowling actions rather than other variables. Both fast and spin bowlers have decreased GHJ IR and increased ER PROM in dominant shoulders compared to non-dominant shoulders.

REFERENCES


ABSTRACT

**Background and Purpose:** Recently, the trend among physical training and rehabilitation professionals is the use of resistance exercise on unstable equipment in order to increase the effort of the agonist and stabilizing muscles. It is unknown if performing exercises on unstable surfaces provides a greater training stimulus as compared to training on a stable training surface. Therefore, the purpose of this research was to compare the effect that push-up training on stable and unstable surfaces had on strength performance in healthy young men.

**Methods:** Thirty subjects with experience in resistance training participated in push-up training two days per week for eight weeks on one of three different surfaces: the floor (Tp), the T-Bow® (TBp) or the BOSU® (Bp).

**Results:** Strength, as measured by one repetition maximum (1-RM) and muscle endurance, as measured by number of pushups performed did not improve significantly (p>0.05) for any of the intervention groups.

**Conclusions:** The addition of unstable surfaces in push-up training does not provide greater improvement in muscular strength and endurance than push up training performed on a stable surface in young men.

**Levels of Evidence:** 3b

**Keywords:** BOSU®, push-up, T-Bow®, unstable surfaces
INTRODUCTION
Push-ups are a very common exercise that can be incorporated into conditioning programs in order to strengthen the upper body. As such, the basic exercise is a closed kinetic chain movement that targets the pectoralis major and triceps brachii, as well as the scapular stabilizing muscles. Moreover, there are other muscle groups (e.g. anterior shoulder and core) that are involved and are important for prehabilitation purposes (e.g. preparation for the act of pitching).

Push-up exercises are commonly used in shoulder rehabilitation, for facilitation of proprioceptive feedback mechanisms, muscle co-contraction, and dynamic joint stability training. Recently, adding an unstable surface while performing the push-up has been suggested in order to increase muscular activity.

One reason for the common utilization of the push-up exercise is due to the relative ease of learning the movement. Additionally, no equipment is necessary for the movement and the exercise can be modified for greater or lesser difficulty depending on the level of physical fitness of the patient. This adaptability is represented by variations that can be used to modify the basic exercise in order to alter the difficulty of the conventional exercise that requires that the hands be placed in a natural position under the shoulder, the back straight, head up, and lower limb straight using the toes as the pivotal point. Authors have used electromyography (EMG) to analyze the different variants of the push-up in order to report the most intensely involved muscles. For example, several push-up variants exist, including the rotational position of the hand-wrist during upper extremity weight bearing, and different spacing of the base hand position. With regard to these variations, Gouvali and Boudolos reported that in the posterior variant of the push-up (+30% of arm-forearm length posterior hand position) the pectoralis major was activated at a higher level than in the standard push-up. Recently, a new variant or modification of the push-up has been examined, namely performing push-ups on an unstable surface. Although it was difficult to monitor the intensity during the push-up with conventional assessment tools, it has been suggested that the perceived exertion scale may be used as a valid intensity assessment. The use of the stability ball as a platform for upper-body resistance training has gained attention in recent years. Current information on the effectiveness of stability balls for athletic performance enhancement and in rehabilitation is contradictory and has been questioned because some unstable resistance training has been shown to induce deficits in measures of muscular performance that could impair the final functional performance. Some researchers have implied that stabilization training may have limited efficacy in altering strength and power due to the relatively low resistance loads utilized during this type of training. However, it must be emphasized that the vast majority of studies have studied intervention programs using resistance training exercise on unstable surfaces for the lower limbs.

A study by Drinkwater et al examined squats on three different surfaces (stable floor, a foam pad, or the BOSU®). Researchers concluded that balance training should be separated from strength and power training. Cressey et al concluded that training on unstable surfaces for lower limbs attenuated functional performance improvements (e.g. sprint and power outcomes) in healthy, trained athletes. In the Cressey et al study, individuals who had completed 10 weeks of training on unstable surfaces had an average reduction in their performance on the T-T test (–2.9%), no change in countermovement jump predicted power (0.0%), only a slight increase in bounce drop jump (0.8%), and some improvements in the 40-yard sprint as compared with those who trained on a stable surface.

Additionally, descriptive studies on training protocols using unstable devices for the upper limbs have shown that such training conditions during the push-up exercise reduces the intensity of agonist muscle activation and does not result in greater recruitment of stabilizing muscles. According to Behm et al the instability training may provide a minor stimulus for limb musculature during exercise but does provide a great deal of core muscle activation.

Finally, contradictory data exists about the effectiveness of resistance training programs implemented using unstable surfaces and few studies have been conducted to compare the effects of stable versus
unstable training on muscles of the upper extremities. Therefore the purpose of this research was to compare the effect that push-up training on stable and unstable surfaces had on strength performance in healthy young men.

**METHODS**

**Subjects**

Thirty recreationally active males were recruited (24.97 ± 3.09 years, 80.60 ± 6.94 kg, 175.43 ± 30.31 cm, 3.33 ± 1.62 years of experience), from a fitness center in Valencia, Spain. They reported a minimum of one year's experience in resistance training and affirmed no use of unstable training of the upper limbs in their resistance training programs. They were considered advanced in resistance training according to guidelines from the ACSM.22 None of the subjects had any upper extremity injury or prior shoulder pathology (e.g. stabilization surgery, impingement, pain) during the previous six months. Subjects with pain, neuromuscular disorders, joint or bone disease, or who were taking some form of performance enhancing medication were excluded (n=12). Prior to inclusion in the study, the subjects were informed about the investigation procedures and the experimental risks. To be included in the research, they were required to sign an informed consent form. The study was approved by the University of Valencia Institutional Review Board for use of human subjects in the spirit of the Helsinki Declaration, after a briefing by the study staff about the purposes, procedures, and risks of the study.

**Procedures**

Familiarization sessions were performed so participants could become accustomed to and learn the proper execution of the BOSU® and T-Bow® push-ups, as well as to determine maximal strength and muscular endurance. Data collection for both anthropometric and testing took place over a period of two weeks with one testing session each week. Testing sessions were carried out in summer, on the same day of the week, at the same time of day and under the same conditions for all tests. All subjects received verbal encouragement throughout all the physical tests. The main researcher and co-researchers collaborated in the procedures and data collection.

Subjects included in the study were randomly assigned to the traditional group (Tp) (n = 10), BOSU® group (Bp) (n = 10) or T-Bow® group (TBp) (n=10). Before the intervention, subjects upper body muscular strength was evaluated using the maximum bench press strength test (1-RM) and muscular endurance was evaluated using the push-up test.24 The intervention lasted 8 weeks, and the subjects trained at a frequency of two days per week. The authors decided that intervention groups should train 2 days per week because: i) there is still a scarcity of studies that control the dose-response in unstable resistance training for strengthening; ii) although subjects were highly trained, it was the first time that they had performed periodized strength training on an unstable surface, and iii) two days is the minimum training frequency suggested for the improvement of strength.1,22

In the intervention phase all groups performed 3 sets of 10 repetitions of push-ups in their respective training conditions. If a subject did not have enough intensity with their own body weight monitored by having at least a score of seven on the OMNI-Res (OMNI-R) scale, external load was added using weight plates that
were placed on the upper back of the subject in increments of 5-kg. The intensity of training was both assessed and maintained throughout the study by using the OMNI-R perception of effort scale. OMNI-R (0-10) was defined as the sense of effort experienced while performing physical work, in this case subjects were told “we want you to rate your perception of exertion in relation to how heavy the exercise feels to you”. The traditional training group performed their push-ups on the stable surface (floor). The BOSU® group performed the push-ups on the BOSU®. The BOSU® was placed so the convex side was in contact with the ground. The T-Bow® group performed their push-ups on the T-Bow® with the convex side on the floor. Unstable resistance training decreases the force in the limbs during dynamic muscular effort because it is necessary for greater muscle stabilization to occur, therefore the external resistance must be decreased. In this sense, Behm and Anderson suggested that it is appropriate to adjust the number of repetitions and the resistance. Although the authors do not know the exact correlations in the intensities between exercises when performed in unstable and stable conditions, previous authors have concluded that using perceived exertion ratings during unstable exercise is a valid method for monitoring the intensity experienced during exercise similarly to monitoring during stable exercises.

In this sense, Behm and Anderson suggested that it is appropriate to adjust the number of repetitions and the resistance. Although the authors do not know the exact correlations in the intensities between exercises when performed in unstable and stable conditions, previous authors have concluded that using perceived exertion ratings during unstable exercise is a valid method for monitoring the intensity experienced during exercise similarly to monitoring during stable exercises.

Each test and intervention session was supervised by the same examiner (ICH-M), who monitored strict compliance with the protocol. Subjects were allowed to continue with their usual lower limb resistance training, cardiovascular training, and upper limb training other than chest press exercises and other exercises (e.g. shoulder press) that included elbow extension.

Testing
All testing was performed in a fitness center. Good intraclass correlation coefficient (ICC) reliability measures have been reported for the push-up test (0.8-0.9) and the bench press test (0.78-0.82).  

1 RM Bench press
After an adequate warm-up of ten bench press repetitions that did not elicit muscular failure (inability to complete the full range of movement repetition for the exercise), a resistance was estimated that would force the participant to fail to be able to complete more than 6 repetitions. The amount of weight that could be moved no more than 6 repetitions was recorded. Participants had a total of three attempts to adjust the weight, every attempt was separated by three minutes of rest. Participants’ 1 RMs were calculated using tables provided by the National Strength and Conditioning Association.  

Push-up muscular endurance test
The muscular endurance push-up test was performed using the criteria outlined in the ACSM’s Health-Related Physical Fitness Assessment Manual. In the standard push-up position, subjects raised the body by straightening the elbows and then lowered the body until the chin touched the mat, without allowing the stomach to touch the mat and then returned to the starting position. The maximum number of push-ups performed consecutively without rest was counted. The test was stopped when the subjects were unable to maintain the appropriate technique for two repetitions, with special emphasis on maintaining neutral positioning of the lumbar spine through the test.

Training Exercises
Push-up
Push-up training was carried out following the model previously established by Beachle & Earle. The starting position was established as follows: back straight and stabilized, the hands shoulder-width apart and the elbows fully extended. From this...
conditions on 1 RM and push-up endurance tests was analyzed using a 2 x 3 repeated-measures ANOVA (dependent variable [1 RM, number of repetitions in push-up endurance test] type of training [Floor, BOSU®, T-Bow®] x time [pre- and post-treatment]). If the results met the assumptions of the model, one-way between-subjects ANOVA was then utilized to detect significant differences between push-up techniques. If significant differences were found, Fisher test (LSD) was used to distinguish if there was a significant difference between push-up techniques. p-values of ≤0.05 were used for all calculations to determine whether statistically significant differences existed.

RESULTS

Individual test means and standard deviations were analyzed (Table 1). No changes were between pre-training and post-training mean scores for endurance testing between conditions: TP (pre = 18.8 ± 5.78 repetitions; post 19.7 ± 6.07 repetitions) BP (pre = 17.4 ± 5.75 repetitions; post 19.9 ± 5.78 repetitions) and TBp (pre = 21.5 ± 6.05 repetitions; post: 24.4 ± 5.94 repetitions), and these results revealed no significant differences between groups. Mean 1 RM results demonstrated (Table 2) no significant improvement by any group: TP (pre = 81.9 ± 11.34 kg; post 82.3 ± 12.45 kg), BP, TBp (pre 76.4 ± 9.83 kg; post 80.2 ± 10.88 kg and pre 82.3 ± 9.16 kg; post 85.8 ± 9.22 kg, respectively), and there were no significant differences between groups. It should be noted that all groups show a trend for improvement.
in endurance and strength performance, even though changes were non-significant.

No statistically significant differences existed between the pre- vs post-treatment endurance test ($F = 2.00; p = 0.154$) or the 1 RM test ($F = 0.67; p = 0.52$) between training conditions.

Similarly, when comparing maximum strength, all groups increased their performance, but these improvements were not statistically significant. There was no significant main effect for type of intervention in 1 RM ($F = 1.74, p = 0.51$).

**DISCUSSION**

Significant differences were not found between treatment groups and the current data appear to support the trend found in similar studies (with training of the lower limbs), where no statistically significant

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**Table 1. Performance in the push-up endurance test in number of repetitions.**

<table>
<thead>
<tr>
<th>Push-up type</th>
<th>Mean repetitions pre-study</th>
<th>Mean repetitions inter-study</th>
<th>Mean repetitions post-study</th>
<th>F value</th>
<th>ANOVA (p Value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional (Tp) n= 10</td>
<td>18.8 ± 5.78 reps</td>
<td>18.8 ± 5.95 reps</td>
<td>19.7 ± 6.07 reps</td>
<td>0.08</td>
<td>0.92</td>
</tr>
<tr>
<td>Bosu (Bp) n= 10</td>
<td>17.4 ± 5.75 reps</td>
<td>19.1 ± 5.19 reps</td>
<td>19.9 ± 5.78 reps</td>
<td>0.01</td>
<td>0.99</td>
</tr>
<tr>
<td>T-Bow (TBp) n= 10</td>
<td>21.5 ± 6.05 reps</td>
<td>22.7 ± 6.44 reps</td>
<td>24.4 ± 5.94 reps</td>
<td>0.52</td>
<td>0.59</td>
</tr>
</tbody>
</table>

*aAnalysis of variance revealed no significant difference for three experimental conditions.

*bAnalysis of variance revealed no significant difference between groups.

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**Table 2. Performance on 1 RM bench press test in kilograms.**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean kilograms pre-study</th>
<th>Mean kilograms inter-study</th>
<th>Mean kilograms post-study</th>
<th>F value</th>
<th>ANOVA (p Value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional (Tp) n= 10</td>
<td>81.9 ± 11.34</td>
<td>82.4 ± 11.32</td>
<td>82.3 ± 12.45</td>
<td>0.01</td>
<td>0.99</td>
</tr>
<tr>
<td>Bosu (Bp) n= 10</td>
<td>76.4 ± 9.83</td>
<td>78.1 ± 12.00</td>
<td>80.2 ± 10.88</td>
<td>0.86</td>
<td>0.43</td>
</tr>
<tr>
<td>T-Bow (TBp) n= 10</td>
<td>82.3 ± 9.16</td>
<td>84.6 ± 9.10</td>
<td>85.8 ± 9.22</td>
<td>0.38</td>
<td>0.68</td>
</tr>
</tbody>
</table>

*aAnalysis of variance revealed no significant difference for three experimental conditions.

*bAnalysis of variance revealed no significant difference between groups.
improvements were reported between groups of highly trained subjects who trained on stable surfaces and groups who trained on unstable surfaces. Previous authors have reported that the use of moderately unstable surfaces did not provide sufficient challenges to affect muscular strength status in highly resistance-trained individuals. This could be a cause of the current results because the subjects in the current study were advanced (individuals with years of resistance training experience) in resistance training. The primary reason for lack of change in muscular strength and endurance could be the insufficient stimulus for muscle strengthening when performing resistance training on unstable surfaces because it is necessary to utilize many muscles to maintain balance and stability. A second possible explanation for the results of the current study is that, as stated in previous reports, there was a reduction in muscle activation of the major muscles when training using an unstable environment. Additionally, many authors have suggested that levels of muscle activity are task-dependent, and using unstable surfaces limits task specificity. Other factors that have been suggested to influence muscle activation while on unstable surfaces include placement of the device, characteristics of the unstable device, and the training status of the subjects.

In a previous study, Cowley et al reported that an unstable platform was effective in increasing strength and work capacity in the barbell chest-press exercise for untrained women. In their study only three weeks of training was performed using three sets of 3–5 repetitions at loads greater or equal to 85% of 1 RM. The load used by Cowley and colleagues was quite different than that used in the current study. The primary difference between these two studies is the placement of the unstable devices. In the current study the unstable devices were placed so that the upper limbs became unstable, whereas Cowley’s study utilized the unstable devices as a replacement for the flat bench, where the lower back rested on the device.

The data from the current study is very similar to that from previous research by Cressey et al. Trained subjects did not increase athletic performance after 10 weeks of training intervention utilizing an unstable surface. The main difference between the studies is that the current study used unstable devices for upper limb training, while Cressey conducted lower limb training. Interestingly, results of both studies were not statistically significant with regard to measures of muscular strength and endurance performance in trained subjects. The results of the current study are similar to previous research that involves unstable resistance training of the lower limb and open kinetic chain upper limb exercise, and is consistent by recent conclusions reported by Behm et al in the Canadian Society for Exercise Physiology. Interestingly, in the current investigation, there was no attenuation in performance of the bench press 1 RM. This data could indicate that training performed on an unstable surface is a sufficient stimulus to maintain strength levels in highly resistance trained subjects if they exercise at the same OMNI-R intensity used during exercises performed on stable surfaces.

The following limitations may have effects on interpreting the results of the study. The lack of an electromyographic (EMG) analysis and the status of the highly trained subjects constitute a limitation at present, as it has been impossible to compare our results with previous studies such as Lehman et al who reported no increase in EMG with the use of elements of instability while performing push-ups. Another limitation was that the subjects were allowed to continue with their resistance training for lower limbs and upper limbs (without similar press-type exercises) which could have interfered with the research results. Since this study was conducted with highly trained individuals no direct clinical comparisons can be made to other populations. The sample size of the current investigation was small, and perhaps a greater number of subjects have demonstrated more robust results.

Future research should be conducted to investigate interventions of longer duration and include the use of core stability tests such as the Biering-Sorensen test, curl-up test, and the side bridge test as suggested by McGill et al in order to assess the effects on the trunk that may occur during upper extremity training using unstable surfaces. Lastly, future researchers could evaluate the effects of upper extremity training on unstable surfaces on the stabilizers of the scapulothoracic articulation and glenohumeral joint in order to determine their contribution to the shoulder complex muscular performance.
Practical applications

Results of the current study may be useful for coaches, rehabilitation professionals, and personal trainers when choosing upper extremity closed chain resistance-training exercises because the current data demonstrated that no significant improvements were obtained after performance of a push-up training program in unstable conditions. Therefore, push-up training using unstable surfaces may need to have schedules implemented in phases designed to maintain maximum strength and muscle endurance for push-ups as compared to a goal of increasing strength and endurance. This might be an alternative for a mesocycle as the muscles of the upper extremities would have to adapt to a new training stimulus or when high loads might be contraindicated.

Unstable devices used during push-up training could be implemented in phases oriented toward enhancement of core strengthening and therapeutic training (e.g. proprioceptive or neuromuscular control objectives).10,13 However, if the decision is made to use unstable surfaces, caution must be taken with persons with shoulder pathology or unstable joints.

CONCLUSION

The results of the current study indicate that the use of unstable surfaces during the push-up exercise in trained subjects leads to comparable, non-significant improvements in the performance of maximum strength and muscular endurance measurements to those seen during push-ups performed on stable surfaces.

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ABSTRACT

Purpose/Background: Researchers have observed differences in muscle activity patterns between males and females during functional exercises. The research methods employed have used various step heights and lunge distances to assess functional exercise making gender comparisons difficult. The purpose of this study was to examine core and lower extremity muscle activity between genders during single-limb exercises using adjusted distances and step heights based on a percentage of the participant’s height.

Methods: Twenty men and 20 women who were recreationally active and healthy participated in the study. Two-dimensional video and surface electromyography (SEMG) were used to assess performance during three exercise maneuvers (step down, forward lunge, and side-step lunge). Eight muscles were assessed using SEMG (rectus abdominus, external oblique, erector spinae, rectus femoris, tensor fascia latae, gluteus medius, gluteus maximus, biceps femoris). Maximal voluntary isometric contractions (MVIC) were used for each muscle and expressed as %MVIC to normalize SEMG to account for body mass differences. Exercises were randomized and distances were normalized to the participant’s lower limb length. Descriptive statistics, mixed-model ANOVA, and ICCs with 95% confidence intervals were calculated.

Results: Males were taller, heavier, and had longer leg length when compared to the females. No differences in %MVIC activity were found between genders by task across the eight muscles. For both males and females, the step down task resulted in higher %MVIC for gluteus maximus compared to lunge, (p=0.002). Step down exercise produced higher %MVIC for gluteus medius than lunge (p=0.002) and side step (p=0.006). ICC3,3 ranged from moderate to high (0.74 to 0.97) for the three tasks.

Conclusions: Muscle activation among the eight muscles was similar between females and males during the lunge, side-step, and step down tasks, with distances adjusted to leg length. Both males and females elicited higher muscle activity for gluteus maximus and gluteus medius as compared to the trunk, hip flexors, or hamstring muscles. However these values were well below the recruitment levels necessary for strengthening in both genders.

Key Words: electromyography, functional exercises, gender, gluteus medius, gluteus maximus

Level of evidence: 4
INTRODUCTION

Functional weight bearing tasks are commonly prescribed as therapeutic exercise to strengthen the lower extremity and simulate activities of daily living. The hip and knee are important to address during rehabilitation because weakness in these anatomical regions have been associated with injuries. Specifically, an increase in patellofemoral syndrome and non-contact anterior cruciate ligament injuries have been found in individuals who have weak hip abductors or delayed activity in portions of the quadriceps muscle.

In an effort to determine muscle activity or joint motions during weight-bearing exercises, numerous kinematic or surface electromyography (SEMG) studies have been performed using the lunge, single limb squat or step tasks. The single limb squat exercise has been reported to be effective in activating gluteus medius ranging from 30% reference voluntary contraction (RVC) to 60% maximum isometric voluntary contraction (MVIC). The SEMG values during the lunge task for the gluteus maximus have ranged from 14%MVIC to 44%MVIC and gluteus medius activity has varied from 15%MVIC to 42%MVIC. The wide range of SEMG values for these tasks may be explained due to differences in subject pool, whether the concentric and eccentric phases of exercise were assessed, if SEMG normalization was performed, and how the tasks were performed.

The large variation of SEMG data during LE functional exercise tasks may also be the result of how men and women differ in controlling the lower extremity during exercise or sport activities. Currently, it is unclear as to whether gender differences exist during performance of functional tasks because of the conflicting data. Many studies support the theory that females have an increased reliance on quadriceps or rectus femoris activity during maneuvers that simulate soccer play, lunges and single-legged squat. In contrast, Beutler et al reported greater knee flexion angles during step-up and squat exercises among men; however quadriceps activity was similar between males and females. Likewise, Cowen and Crossley found no gender differences in quadriceps and gluteus medius muscle activity during a stepping task. The inconsistency within the literature may be due to the lack of task standardization among studies. For example, Dwyer et al standardized the lunge distance based on leg length but did not normalize the step up and over task. Others have also used the same box heights for males and females despite differences in their actual heights.

Overall gender differences that occur during athletic maneuvers such as running and cutting, landing, jumping and hopping have been well documented, yet there are few studies comparing gender performance during common functional tasks. The abundance of evidence associated with gender differences during dynamic running and cutting tasks is, in part, due to researchers attempting to better understand the mechanism linked to athletic-related injuries such as those that occur in the anterior cruciate ligament. Although single-limb weight-bearing exercises do not simulate the same dynamic motions as game-like tasks, assessment of muscle performance during functional tasks may be important for injury prevention and optimal rehabilitation Therefore, the purpose of this study was to examine core and lower extremity muscle activity between genders during single-limb exercises using adjusted distances and step heights based on a percentage of the participant's height. It was hypothesized that there would be no significant differences between genders for the %MVIC of the selected trunk, hip, and thigh muscles during the three functional tasks.

METHODS

Subjects

Forty recreationally active subjects, 20 males (mean age = 23.2 ± 1.9 yrs, height = 1.8 ± .09 cm, bodyweight = 87.8 ± 20.0 kg) and 20 females (mean age = 22.4 ± 1.8 yrs, height = 1.6 ± .07 cm, bodyweight = 42.5 ± 7.0 kg) with no known musculoskeletal injuries participated in the study. Recreationally active was defined as someone who participated in recreational activities three to five times a week for at least 30 minutes per day. Subjects were recruited by flyers distributed throughout the university and surrounding community. The exclusion criteria consisted of anyone diagnosed with musculoskeletal, cardiovascular, vestibular, visual, or balance disorders and a history of back injury, back pain or back
deformity requiring medical treatment. The university IRB approved the study protocol and written informed consent was obtained from all individuals prior to participation.

**Instrumentation**

Muscle activity data was collected using an 8-channel surface telemetry EMG system (Noraxon Myo-system 900 EMG system, Noraxon USA, Inc., Scottsdale, AZ) and a 2-D video recording was obtained during performance of the test movements in order to assist in subsequent analysis. The digital video camera (Canon Optura50, Canon Inc., Lake Success, NY) was placed at the height of the subject's knee, three meters anterior to the subject for a frontal plane recording for the step down and side-step tasks and sagittal plane recording for lunge. A transmitter belt unit powered by a 9V battery was worn to collect surface electromyography (SEMG) signals. Raw SEMG data were sampled at 1000Hz for each of the eight muscles on the dominant limb. The unit was set with a differential input impedance of greater than 10 MΩ, a gain of 1000, and a common-mode rejection ratio of 115 dB.

**Procedures**

Silver-silver chloride snap single surface pregelled electrodes (Noraxon USA, Inc., Scottsdale, AZ) were placed in a bipolar configuration on the skin of the dominant leg and torso of same side of dominant limb. The dominant leg was defined the preferred kicking leg. The electrodes were positioned parallel to the muscle fiber orientation with an interelectrode distance of approximately 2.0 cm. The skin was prepped by shaving, abrading, and cleaning with isopropyl alcohol wipes prior to electrode placement. The ground lead was placed on the subject's anterior superior iliac spine (ASIS) contralateral to the subject's dominant leg. Each subsequent lead was positioned as defined by Cram and Rainoldi et al on the subject's dominant side. The rectus femoris (RF) electrodes were placed midway between the ASIS and base of the patella. Electrodes for the upper fibers of the rectus abdominus (RA) were placed at the midpoint between the umbilicus and xyphoid process, and three cm lateral with the electrode aligned longitudinally in parallel with the fibers of the muscle. Electrode placement for external oblique (EO) was at the level of the umbilicus at an oblique angle (45 degrees) between the inferior costal margin and ASIS. The electrodes for the tensor fascia latae (TFL) were placed two fingerbreadths distal to the ASIS and two fingerbreadths medial to the greater trochanter. Electrodes for the anterior gluteus medius (GMed) were approximately three cm inferior to the iliac crest. Electrodes for the erector spinae (ES) were placed in a vertical direction two centimeters lateral to the spines processes between L3-L4. Electrodes for the lower fibers of the gluteus maximus (GMax) were placed inferior and medial to a line drawn between the PSIS and the posterior greater trochanter. The electrodes for biceps femoris (BF) were placed midway between the ischial tuberosity and the crease of the patella fossa.

Following rest period, subjects performed a brief warm up of lower extremity flexibility exercises. After the warm-up, the experimental protocol was described using verbal instructions and demonstration of each exercise. Subjects were given the opportunity to practice the forward lunge, side-step lunge, step down exercises for ten repetitions. Participants completed each of the three unilateral functional exercises (step down, forward lunge, and side-step lunge) in a randomized order. For each activity, the subjects performed two sets of 10 repetitions at a pace of 80 bpm using a metronome. This rate was equal to 20 steps/lunges per minute (four clicks for each repetition). Each step or lunge repetition was three seconds in duration. The initial set was used as a practice trial and second set was used for data analysis. Following each practice session, the subjects were given a 30-second rest break.

**Step down.** Subjects were asked to step down from a height adjusted to 25% (± 5%) of their leg length based on previous research. The step height was determined by measuring limb length on the dominant limb with the subject in a supine position on a mat table. A tape measure was placed on the most inferior aspect of the anterior superior iliac spine and most distal portion of the medial malleolus. A single measurement of the total leg length was recorded in millimeters, and multiplied by 25% to determine step height for each subject. The subject stood on the step with hands on hips and feet shoulder width apart. The dominant leg served as
the stance leg and opposite limb moved in an anterior direction toward the ground, until the heel of the non-dominant foot contacted the ground, and then returned to initial position (Figure 1).

**Forward lunge.** Subjects were instructed to stand with their feet shoulder width apart. The distance that the subjects stepped forward during the lunge was adjusted to 65% (±5%) of their leg length. This distance was chosen based on pilot testing in which the final position could be performed comfortably with the dominant limb held vertically while maintaining the knee over the foot. The total leg length recorded in millimeters was multiplied by 65% to determine forward lunge distance for each subject. A tape measure was placed on the floor and the subject was asked to perform the forward lunge with their dominant leg so that the midpoint of the heel reached the adjusted distance. Participants were also instructed to make full foot-flat while maintaining hip and knee flexion to 90 degrees and avoiding ground contact with the non-dominant knee. The subjects were asked to return to starting position with full knee extension of the lunge leg (Figure 2).

**Side-step lunge.** Subjects were instructed to stand with their feet shoulder width apart. The distance that the subjects stepped sideways during the lunge was adjusted to 80% (±5%) of their leg length. This distance was chosen based on pilot testing in which the final position could be performed with the non-dominant limb held in full knee extension comfortably while the dominant limb maintain the knee over the foot. The total leg length recorded in millimeters was multiplied by 80% to determine side-step lunge distance for each subject. The non-dominant leg remained in full knee extension throughout the activity. A tape measure was placed on the floor and the subject was asked to perform a side-step with their dominant leg so that the midpoint of the heel reached the adjusted distance (Figure 3). The repetition was completed when the subject returned to the initial position.

**Electromyography Analysis**
Three maximal voluntary isometric contractions (MVIC) were performed in standard manual muscle test positions for each subject for the eight muscles analyzed. Following MVIC data collection, partici-
pants rested for five minutes prior to the functional exercise testing. Each test for MVIC was held for five seconds, was followed by three second rests between contractions, and was performed three times. There was a 30-second rest between muscles tested. The rectus femoris was tested with the subject sitting with knees over the table, and manual resistance applied approximately 40 degrees from full knee extension. The rectus abdominis muscle was tested with trunk moving in a flexed position as a partial curl-up, and resistance applied to bilateral shoulders. The external oblique abdominal was tested with the subject in a hook lying position with the trunk directed toward the opposite knee. The tensor fascia latae was tested in a supine position, the hip placed in an abducted, flexed, and medial rotated position with the knee extended. Manual resistance was applied at the distal lower leg as the limb moved into extension and adduction. The gluteus medius was assessed in a sidelying position, with the hip in neutral rotation and slightly extended with manual resistance applied at the distal lower leg as the hip actively moved into abduction. The subject was positioned in prone for gluteus maximus, with the knee flexed to 90 degrees and the hip fully extended. Manual resistance was applied on the lower part of the posterior thigh as the hip moved into extension. The erector spinae was tested with the subject in prone and trunk off the edge of the table at the level of the ASIS. A second investigator stabilized the lower extremity just above the ankle as the subject extended the lumbar spine to neutral and resistance applied to the posterior scapula. The biceps femoris was tested in prone position with knee flexed to 45 degrees and lower leg in external rotation. The average SEMG amplitudes collected during the functional exercises were later normalized to the highest MVIC value obtained during manual muscle tests, and expressed as percentage of MVIC (%MVIC).

The receiver converted the signal from analog to digital through an external USB A/D converter, and signals were displayed on a computer monitor. The amplifier bandwidth frequency ranged from 10Hz highpass to 500 Hz lowpass. The SEMG signals were directed through a 12-bit analog-digital converter (Telemyo, Norazon USA, Inc, Scottsdale, AZ). The raw data was stored in a personal computer and Myoresearch 2.10 software (Noraxon USA, Inc, Scottsdale, AZ) was used to process and analyze the data. The raw SEMG signals were obtained during the 4th through 6th repetitions. Each repetition lasted three seconds which captured the start of the movement and return to original position. The onset of each of the eight muscle contractions during the three tasks were marked by the start of motion as noted on the video recording when the muscle SEMG amplitude was 10 μV of baseline. The raw SEMG signals were processed using a full-wave rectification and a root-mean-square algorithm at a time constant of 300 milliseconds.

**STATISTICAL ANALYSIS**

The average peak MVICs generated from each of the eight manual muscle tests were used to normalize the SEMG amplitudes for each muscle and expressed as %MVIC. Descriptive statistics, ANOVAs, and ICCs with 95% confidence intervals were calculated using SPSS version 18.0 (SPSS, Inc, Chicago, IL) software. Descriptive statistics were reported as means ± standard deviations for all subjects. One way ANOVAs were used to determine differences existed for age, height, and body mass index (BMI). Repetitions 4-6 of each exercise were converted to a mean amplitude for the eight muscles, and the overall mean was used for SEMG was used for analysis. Shapiro-Wilk's W-test was applied to examine normality in the distribution of data. The normalized SEMG values were analyzed using 8 separate 2 × 3 ANOVAs (normalized SEMG values for 8 muscles), gender (male and female) and task (lunge, side-step, step-down). Post-hoc comparisons of the means of interest were conducted using the Bonferroni procedure.

The intraclass correlation coefficients (ICC3,3) and 95% confidence intervals (CIs) were calculated across the middle three repetitions (4-6 repetitions) for each muscle and exercise to confirm consistency of SEMG values. The strength of the correlations were classified as: 0-.25 “little,” .26-.49 “low,” .50-.69 “moderate,” .70-.89 “high,” and .9-1.0 “very high.” Standard error of the mean (SEM) was calculated by multiplying the standard deviation of the %MVIC for each muscle by the square root of 1 minus the ICC3,3 to describe the precision of the measurement. The significance level was set a priori at p<0.02, (.05/3).
RESULTS

Leg length, height and weight were significantly greater for males as compared to females (Table 1). The men had 0.07 m longer leg length as compared to women. The males were also 0.2 meters taller and weighed 20 kilograms more as compared to females.

The ANOVA (gender by task) indicated no significant difference existed among the eight muscles and results are presented in Table 2. A significant effect was found among two of the eight muscles, GMax %MVIC, (p=0.004) and GMed %MVIC, (p=0.002) for both males and females. Post hoc testing

<table>
<thead>
<tr>
<th>Table 1. Participant Characteristics</th>
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<tbody>
<tr>
<td>Age (y)</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>Males</td>
</tr>
<tr>
<td>Females</td>
</tr>
</tbody>
</table>

Data expressed as means (± standard deviation)
* Indicates males were significantly greater in height, leg length, and body weight than females, p=0.0001.

<table>
<thead>
<tr>
<th>Table 2. Comparison of means (± standard deviation) for electromyographic activity of eight muscles during the three tasks for males and females.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lunge</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Rectus Femoris</td>
</tr>
<tr>
<td>Rectus Abdominis</td>
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<tr>
<td>External Oblique</td>
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<tr>
<td>Erector Spinae</td>
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<tr>
<td>Tensor Fascia Latae</td>
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<tr>
<td>Biceps Femoris</td>
</tr>
<tr>
<td>Gluteus Medius</td>
</tr>
<tr>
<td>Gluteus Maximus</td>
</tr>
</tbody>
</table>

Data expressed as means (± standard deviation) percentage of maximum voluntary isometric contraction (%MVIC).
* For gluteus medius muscle, statistically higher %MVIC for step down compared to lunge (p=.002) and side step (p=.006)
† For gluteus maximus muscle, statistically higher %MVIC for step down compared to lunge, (p=.002)
indicated that the step down task resulted in higher GMax %MVIC activity compared to lunge, (p = .002). The step down exercise was also higher for GMed %MVIC than lunge (p = .002) and side step (p = .006).

The reliability analysis (ICC3,3) across the three repetitions for each exercise activity resulted reliability values for the lunge ranging from 0.74 to 0.97, side-step (.83 to .99), and step down (.82 to .96) (Tables 3 and 4). These values indicate moderate to high

### Table 3. Mean differences expressed as %MVIC during the three tasks for gluteus medius and gluteus maximus muscles.

<table>
<thead>
<tr>
<th></th>
<th>Lunge</th>
<th>Side-Step</th>
<th>Step-Down</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gluteus Medius</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lunge</td>
<td>/</td>
<td>-.34</td>
<td>-1.79*</td>
</tr>
<tr>
<td>Side-Step</td>
<td>.34</td>
<td>/</td>
<td>-1.45*</td>
</tr>
<tr>
<td>Step-Down</td>
<td>1.79*</td>
<td>1.45*</td>
<td>/</td>
</tr>
<tr>
<td>Gluteus Maximus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lunge</td>
<td>/</td>
<td>-.95</td>
<td>-2.00*</td>
</tr>
<tr>
<td>Side-Step</td>
<td>.95</td>
<td>/</td>
<td>-1.05</td>
</tr>
<tr>
<td>Step-Down</td>
<td>2.00*</td>
<td>1.05</td>
<td>/</td>
</tr>
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</table>

Data expressed as mean difference using Bonferroni test- mean difference (I-J) and significance.
*indicates significant difference

### Table 4. Intrarater repeatability and SEM for three exercises and eight muscles among females.

<table>
<thead>
<tr>
<th></th>
<th>Lunge</th>
<th>Side-Step</th>
<th>Step-Down</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>ICC3,3</td>
<td>SEM</td>
<td>ICC3,3</td>
</tr>
<tr>
<td>Rectus Femoris</td>
<td>.74</td>
<td>.97</td>
<td>.91</td>
</tr>
<tr>
<td>Rectus Abdominus</td>
<td>.94</td>
<td>.51</td>
<td>.95</td>
</tr>
<tr>
<td>External Oblique</td>
<td>.90</td>
<td>1.15</td>
<td>.95</td>
</tr>
<tr>
<td>Erector Spinae</td>
<td>.94</td>
<td>.90</td>
<td>.95</td>
</tr>
<tr>
<td>Tensor Fascia Latae</td>
<td>.94</td>
<td>.45</td>
<td>.88</td>
</tr>
<tr>
<td>Biceps Femoris</td>
<td>.86</td>
<td>.84</td>
<td>.87</td>
</tr>
<tr>
<td>Gluteus Medius</td>
<td>.76</td>
<td>.82</td>
<td>.83</td>
</tr>
<tr>
<td>Gluteus Maximus</td>
<td>.87</td>
<td>.84</td>
<td>.86</td>
</tr>
</tbody>
</table>
reliability across all muscles among the exercise tasks between males and females.42 The SEM values presented in Tables 3 and 4 ranged from .45%MVIC to 1.15%MVIC across the three exercises.

**DISCUSSION**

The purpose of the current study was to examine lower extremity activation patterns between men and women performing three functional tasks. Each of the tasks performed was unilateral weight bearing, and the excursion distances were adjusted to a percentage of the subject’s leg length. The results of the current study support the hypothesis that males and females would elicit similar muscle activity among the tasks when the excursion distances were adjusted to a percentage of the subject’s leg length. The current study indicated no gender differences among the three tasks using the adjusted excursion distances based on a percentage of leg length. The authors felt adjusting the step height or lunge distance based upon the subject’s leg length was important because of height differences between the males and females. The female subjects were significantly shorter (1.6 ± .07 m) and had shorter leg length (.87 ± .05 m) compared to the height of the males (1.8 ± .09m) and their leg length, (.94 ± .05 m). In contrast, other authors have reported sex differences in muscle activity or limb positioning, however, chose not to modify the task heights.11,26,27 For example, Dwyer et al did not adjust the step height for their step-up-and-over exercise despite the men being 1.4 m taller compared to females.11 Similarly, Zazulak et al maintained the same box height during testing, even though the females were 1.3 m shorter than the males.26 Others have studied muscle activity requiring men and women to drop land from a 6 m box.27 These authors did not report statistical analysis of subject demographics, however the women were 1.9 m shorter compared to males. It may be that in addition to different intrinsic muscle or joint position strategies, women compensate because of the greater relative step height or jump distances related to their shorter stature.

The authors of the current study selected unilateral weight bearing exercises including the forward and side-step lunge and step-down activity for examination. Since stair climbing is a very common task, many studies use a standard step height of 20 cm to 21 cm.6,9,11,15,21 However, step heights of 15 cm14,20 19 cm,17 30.5 cm,26 and 25% of leg length41 have been used in research. The distance covered during a lunge has also varied from a comfortable distance7 to full range of motion,9,11 and to 90 degrees of knee flexion.10 These variations of excursion distances and

<table>
<thead>
<tr>
<th></th>
<th>Lunge</th>
<th>Side-Step</th>
<th>Step-Down</th>
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<tbody>
<tr>
<td>Rectus Femoris</td>
<td>.92</td>
<td>.97</td>
<td>.90</td>
</tr>
<tr>
<td>Rectus Abdominus</td>
<td>.91</td>
<td>.90</td>
<td>.93</td>
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<td>External Oblique</td>
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<tr>
<td>Erector Spinae</td>
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<tr>
<td>Tensor Fascia Latae</td>
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<td>Gluteus Medius</td>
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<td>Gluteus Maximus</td>
<td>.97</td>
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</table>

Table 5. Intrarater repeatability and SEM for three exercises and eight muscles among males.
step heights make it difficult to compare functional tasks across studies.

The authors found that the average SEMG activity ranged among the participants from 10 to 14%MVIC for five lower extremity muscles. Trunk muscle activity, specifically for external oblique, rectus abdominis, and erector spinae muscles ranged between 12 to 15%MVIC. Ekstrom et al. found that the core muscle SEMG activity for rectus abdominis was 7% and external oblique at 17%MVIC. The percent MVIC differences between this study and others may be the result of possible variations among lunge distances, trunk position, electrode placement, or which portion of the muscle was assessed.

The muscle activity variations may also be related to time differences chosen to process SEMG amplitudes. The current study used a 3-second time period to collect raw SEMG signals which were then smoothed over 300 ms window. Dwyer et al. also collected raw SEMG signals for three seconds, however they smoothed over 500 ms window. Others have processed SEMG signals with varying window lengths from 15 ms, 20 ms to 55 ms. Cram suggested that the typical SEMG window range from 100 ms to 200 ms. Others have proposed that the optimal window length for static and dynamic contractions should range from 200 ms to 300 ms, respectively. However, these authors assessed the middle deltoid and acknowledged that the 200 to 300 ms values may fluctuate based on the muscle group under study. Further study of SEMG processing may be helpful to determine the preferred window length for weight-bearing tasks requiring dynamic contractions in lower limb musculature.

Identifying eccentric and concentric components of muscle activity is interesting because it has been found that concentric contraction results in higher EMG amplitude and lower mean SEMG frequency compared to eccentric contraction. Several SEMG studies have differentiated concentric and eccentric muscle activity during weight bearing tasks by kinematic analysis of joint positions and ground reaction force data. The current study did not employ kinematic or kinetic analysis, thus the authors are unable to accurately identify concentric or eccentric contractions during the unilateral weight bearing tasks. Therefore, eccentric and concentric phases were combined during the SEMG analysis which is similar to other studies.

The gluteus medius muscle was found to be statistically most active during the step down task (14%MVIC) compared to either the side-step (13%MVIC) or lunge (12%MVIC) for both the men and the women. The gluteus maximus muscle elicited higher activity when the participants performed the step down task (13%MVIC) as compared to the lunge (10-11%MVIC). Despite muscle activity differences, all of the SEMG values fell well below the 40% to 60% intensity levels necessary for strengthening. In general, the trunk muscles responded similarly regardless of exercise and the values ranged from 11 to 15%MVIC. Thus, taking into account the low SEMG activity levels for both the core and lower extremity muscles observed during the three functional tasks might help guide clinicians in selecting interventions.

A significant limitation to the current study is the lack of range of motion and strength data. This investigation also did not assess trunk and lower extremity flexibility. Another possible limitation to the current study is that true maximum effort was not produced by the subjects during muscle testing used to establish the MVIC. In order to motivate the subjects, verbal encouragement was provided to everyone. While the current study recruited both men and women for this study, the participants were relatively young, healthy, and recreationally active.

Cross-talk with the use of SEMG electrodes from adjacent muscles may be a limitation, as in any SEMG study. The current investigation used standardized electrode placement for each of the muscles assessed in our study. It has been suggested that using the standardized method for SEMG placement improves the recordings at each of the muscles sites.

CONCLUSION

Gender differences in SEMG measures of muscle activity among the three selected weight bearing single-limb exercises were not found. This may be due, in part to using adjusted distances and step heights based on the participants’ leg length. The information gained from this study has raised questions as to how muscle patterns are affected using normalized...
distances based on leg length among women. This study also demonstrated that the forward or side-step lunge and step down tasks demand low levels of core and lower extremity muscle activation. While gluteus maximus and gluteus medius were more active during these tasks compared to the trunk, hip flexor, or hamstring muscles, they still were well below the intensity necessary for strengthening.

**REFERENCES**


ABSTRACT

**Background/Purpose:** While elastic resistance training, targeting the upper body is effective for strength training, the effect of elastic resistance training on lower body muscle activity remains questionable. The purpose of this study was to evaluate the EMG-angle relationship of the quadriceps muscle during 10-RM knee-extensions performed with elastic tubing and an isotonic strength training machine.

**Methods:** 7 women and 9 men aged 28-67 years (mean age 44 and 41 years, respectively) participated. Electromyographic (EMG) activity was recorded in 10 muscles during the concentric and eccentric contraction phase of a knee extension exercise performed with elastic tubing and in training machine and normalized to maximal voluntary isometric contraction (MVC) EMG (nEMG). Knee joint angle was measured during the exercises using electronic inclinometers (range of motion 0°-110°).

**Results:** When comparing the machine and elastic resistance exercises there were no significant differences in peak EMG of the rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM) during the concentric contraction phase of a knee extension exercise performed with elastic tubing and in training machine. However, during the eccentric phase, peak EMG was significantly higher (p<0.01) in RF and VM when performing knee extensions using the training machine. In VL and VM the EMG-angle pattern was different between the two training modalities (significant angle by exercise interaction). When using elastic resistance, the EMG-angle pattern peaked towards full knee extension (0°), whereas angle at peak EMG occurred closer to knee flexion position (90°) during the machine exercise. Perceived loading (Borg CR10) was similar during knee extensions performed with elastic tubing (5.7±0.6) compared with knee extensions performed in training machine (5.9±0.5).

**Conclusion:** Knee extensions performed with elastic tubing induces similar high (>70% nEMG) quadriceps muscle activity during the concentric contraction phase, but slightly lower during the eccentric contraction phase, as knee extensions performed using an isotonic training machine. During the concentric contraction phase the two different conditions displayed reciprocal EMG-angle patterns during the range of motion.

**Level of Evidence:** 5

**Key words:** Electromyography, strength training, quadriceps, perceived exertion

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INTRODUCTION
Reduced knee-extension strength is commonly reported in over-use knee pathologies, for example, the patello-femoral pain syndrome,1 and after total knee replacement,2,3 suggesting that strength training of the quadriceps muscle is needed.4 Accordingly, knee joint replacement and knee joint pain is often associated with muscular atrophy,5 and central activation failure3,6,7 resulting in reduced functional performance, potential for future injury and increased risk for long-term sickness and work-related absence.8,9 Heavy resistance training during a prolonged training period yields muscular hypertrophy,10–12 gains in strength,13–15 increased neuro-muscular (efferent) drive11,16,17 and reduced pain.18 However, the availability of strength training equipment is often a limiting factor during rehabilitation and training interventions.19

A growing interest in developing simple and effective training methods convenient for exercising at the workplace, in the hospital, at home or at the training field18–20 has been emerging for quite some time. High-intensity strength training using elastic resistance has shown to be equally effective in activating smaller muscles in the neck, shoulder, and arm when compared to similar training exercises performed isotonically with dumbbells.21,22 The effect of elastic resistance training on larger muscle groups such as the quadriceps, however, remains largely unexplored. Furthermore, development of simple and effective training exercises feasible for use during rehabilitation of knee pathologies is needed.

Electromyography (EMG) and electro-goniometry obtained during resistance training and physical rehabilitation exercises provide valuable information on temporal and spatial muscle activation strategies during different angular phases of the exercise through range of motion. Whereas the EMG - joint angle relationship is well described for conventional (i.e. using dumbbell or machine) isoinertial strength exercises,23 only one recent study has investigated the EMG-angle pattern during elastic resistance exercise.24 Aboodarda et al. compared the EMG angle-relationship during knee extension using elastic resistance and a Nautilus isotonic machine (Nautilus, Vancouver, WA) and showed that the average vastus lateralis muscle activity was similar during the two exercise modalities. Nevertheless, the EMG-angle relationship of multiple prime mover muscles (rectus femoris, vastus medialis and vastus lateralis) as well as the antagonist/ synergists muscle activity during knee extensions remains un-investigated. An imbalance in the synergistic activation ratio of the vastus medialis (VM) and vastus lateralis (VL) may contribute to knee injuries such as patellafemoral pain syndrome.25,26 Accordingly, exercises with higher VM to VL ratios may be preferred during rehabilitation.23 Although conventional knee extensions performed in an isotonic machine may not preferentially activate the VM over the VL,23 the VM to VL activation ratio may differ throughout range of motion during knee extensions performed using elastic resistance.

The purpose of this study was to evaluate the EMG-angle relationship of the quadriceps muscle during 10-RM knee-extensions performed with elastic tubing and an isotonic strength training machine.

MATERIALS AND METHODS
Experimental Approach to the Problem
Muscle activity and perceived loading (rated on a Borg CR10 scale) during leg strengthening exercises performed in a training machine or with elastic resistance were evaluated using a cross-sectional design. For each individual muscle, EMG muscle activity of each of the dynamic muscle contraction was normalized to the amplitude elicited during a maximal voluntary isometric contraction (MVC).

Subjects
The study was performed in Copenhagen, Denmark. A group of 16 untrained adults (7 women and 9 men) were recruited from a large workplace with various job tasks. Exclusion criteria were blood pressure above 160/100, disc prolapse, or serious chronic disease. Table 1 displays the subject demographics. All participants performed both conditions of knee extension testing, with elastic resistance and in the isotonic training machine. All subjects were informed about the purpose and content of the project, and gave written informed consent to participate in the study, which conformed to The Declaration of Helsinki, and was approved by the Local Ethical Committee (H-3-2010-062).

Exercise equipment
Two different types of knee-extension strength-training equipment were used; 1) elastic tubing with
resistances ranging from light to very heavy (red, green, blue, black, silver/gray colors, TheraBand, Akron, USA) and 2) an isotonic knee-extension machine (Vertical seated knee extension, Technogym, Gambettola, Italy).

**Exercise description**
A week prior to testing, the participants performed a 10 repetition maximum (10 RM) test for the two exercises. During the elastic resistance exercise the 10 RM loading was found using one or a combination of several elastic tubes with resistances ranging from light to very heavy (red, green, blue, black, gray colors). All exercises were performed unilaterally using the dominant leg (preferred leg) as the exercising leg. A week later, on the day of EMG measurements, participants warmed up with submaximal loads, and then performed three consecutive repetitions for each exercise, using the predetermined 10 RM load, to avoid the influence of fatigue on the subsequent exercises. Exercises were performed in a controlled manner at a slow constant speed [participants attempted to perform each repetition in ~3 sec (eccentric phase: ~1.5 sec and concentric phase: ~1.5 sec)]. The order of exercises was randomized for each subject, and the rest period between different exercises was approximately five minutes. The exercises are shown in Figure 1 and described in detail below:

**Knee extension with elastic resistance (Fig. 1a & 1b).** The participant was sitting on a high chair; facing away, from a wooden bar (elastic fixation point located 10 cm above the floor and with a horizontal distance of ~1.5 m from the chair to the bar) with both legs flexed at ~90° knee joint angle and a 90° hip flexion. The elastic tubing was fixated to the participant's ankle on one end (1 finger above the medial malleoli), and the other end was attached to the bar. The elastic band was then stretched to ~200% of the initial length. The participant started extending the knee from the flexed knee position (~90° knee joint angle) (concentric phase) until full extension (~0° knee joint angle), and then returned to the flexed knee position (eccentric phase).

**Isolated knee extension in machine (Fig. 1c & 1d).** The participant was seated in a Technogym knee extension machine with the leg flexed at ~90° knee joint angle and a 100° hip flexion. The machine's lever arm was fixated 1 finger above the medial malleoli. The participant started by extending the knee (concentric phase) until full extension was achieved (~0° knee joint angle), and then flexed the knee (eccentric phase) returning to the ~90° knee joint angle.

**Inclinometer sampling and analysis**
Knee joint angle was continuously measured using two electronic inclinometers (2D DTS inclination sensor, Noraxon, Arizona, USA) placed at the lateral side of the tibia and femur, respectively. The inclinometer data were synchronously sampled with the EMG data, using the 16-channel 16-bit PC-interface receiver (TeleMyo DTS Telemetry, Noraxon, Arizona, USA). The dimension of the probes was 3.4 cm x 2.4 cm x 3.5 cm. During subsequent analysis, the inclinometer signals were digitally lowpass filtered using a 4th order zero-lag Butterworth filter (3 Hz cutoff frequency).

The momentary knee joint angle was calculated as the difference in angular position, with respect to the gravitational line, between the tibia and femur inclinometers. Knee joint angles ranged from a 90° flexed position to a 0° full knee extension. The concentric and eccentric phases were defined as periods with negative or positive angular velocity, respectively, (going from 90°-0° or 0°-90°, respectively). Angle at peak EMG was calculated within the concentric and eccentric phase.

**EMG signal sampling and analysis**
EMG signals were recorded from 10 leg, abdominal, and lower back muscles, including: vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF)
(prime movers for knee extension) and biceps femoris, semitendinosus, adductors, gluteus medius, right erector spinae, right external oblique and the right rectus abdominis (non-prime movers for knee extension). A bipolar surface EMG configuration (Blue Sensor N-00-S, Ambu A/S, Ballerup, Denmark) with an inter-electrode distance of 2 cm were used. Before affixing the electrodes, the skin of the respective area was prepared with scrubbing gel (Acqua gel, Meditec, Parma, Italy) to effectively lower the impedance to less than 10 kΩ. Electrode placements for all muscles followed SENIAM recommendations (www.seniam.org).

The EMG electrodes were connected directly to wireless probes that pre-amplified the signal (gain 400) and transmitted data in real-time to a 16-channel 16-bit PC-interface receiver (TeleMyo DTS Telemetry, Noraxon, Arizona, USA). The dimension of the probes was 3.4 cm x 2.4 cm x 3.5 cm. Data was collected at a sampling rate of 1500 Hz. Common mode rejection ratio was higher than 100 dB.

During later off-line analysis, all raw EMG signals obtained during MVCs as well as during the exercises were digitally filtered by a Butterworth 4th order high-pass filter (10 Hz cutoff frequency). For each individual muscle, maximal moving root mean square (RMS) (500 ms constant) EMG was used to identify peak EMG within the concentric and eccentric phase whereas the RMS of the highpass filtered EMG signal was calculated within each 10° angle interval (0°-10°, 10°-20°, ... 80°-90°) of the concentric and eccentric phases and then normalized to the maximal moving
RMS (500-ms time constant) EMG obtained during MVC.²¹,²⁷,²⁸ Contraction time was calculated according to procedures previously described in.²⁷

Maximal voluntary isometric contraction (MVC)
Prior to the dynamic exercises described above, isometric MVCs were performed, according to standardized procedures during 1) static knee extension and 2) flexion manoeuvres (positioned in a Biodex dynamometer: knee angle: 70° and hip angle: 110°), 3) hip adduction (lying flat on the back and pressing the knees against a solid ball), 4) hip abduction (lying flat on the back and pressing the knees outwards against a rigid band) and 5) hip extension (lying flat on the stomach with the knee flexed (90°) and pressing the foot upwards against the instructors hands), and 6) trunk extension and 7) trunk flexion (in standing posture and pelvis fixated the trunk was extended against a rigid band) to induce a maximal EMG response in the tested muscles.²⁹ Two MVCs were performed for each muscle, and the trial with the highest RMS EMG value was subsequently used for normalization of the RMS EMG signals obtained in the resistance exercises. During the MVCs, subjects were instructed to gradually increase muscle contraction force towards maximum over a period of two seconds, sustain the MVC for three seconds, and then slowly release the force again. Strong and standardized verbal encouragement was given during all trials.

Perceived loading
Immediately after each set of exercise, the Borg CR10 scale³⁰ (Appendix 1) was used to rate perceived loading during the resistance exercise. We have previously validated this scale in the evaluation of neck/shoulder resistance exercises with elastic resistance.²¹

Statistical analysis
A two-way repeated measures analysis of variance (Proc Mixed, SAS version 9, SAS Institute, Cary, NC) was used to determine if differences existed between exercises and range of knee joint motion for each muscle and contraction mode (concentric or eccentric), vastus medialis to vastus lateralis activation ratio, perceived loading (BORG) and contraction time. Factors included in the model were Exercise (elastic resistance and machine) and knee joint angle interaction. The analysis was controlled for gender and age. Normalized EMG was the dependent variable. Values are reported as least square means (SE) unless otherwise stated. P-values ≤0.05 were considered statistically significant.

A priori power analysis showed that 16 participants in this paired design were sufficient to obtain a statistical power of 80% at a minimal relevant difference of 10% and a type I error probability of 1%, assuming standard deviation of 10% based on previous research in the authors laboratory.³¹

RESULTS
Normalized EMG
Figure 2 shows the normalized EMG-angle relationship for the quadriceps muscles during knee extension exercises performed in machine or with elastic resistance during the 0-90° knee joint range of motion. There was no significant difference in maximal EMG between machine and elastic resistance exercise for the prime movers for knee extension (rectus femoris, vastus lateralis, vastus medialis) during the concentric contraction phase (Table 2). However, during the eccentric phase, peak EMG was significantly higher (p<0.01) in RF and VM when performing knee extensions using the training machine compared with elastic resistance.

There was a significant exercise by knee joint angle interaction (P<0.01). The EMG-knee joint angle relationships for the two investigated vasti were different between training modalities. For the machine, the concentric phase EMG-amplitude peaked near maximal knee flexion (60.2°±4.3 and 60.5°±4.3 for the VL and VM, respectively) and decreased towards full knee extension, whereas the opposite pattern was seen for the elastic tubing (angle at peak EMG: 33.8°±4.3 and 34.3°±4.3 for the VL and VM, respectively). Irrespective of training condition, angle and contraction mode, the VM to VL EMG ratio never exceeded 1.00 and was similar between the two exercise conditions.

All muscles besides the prime movers RF, VL and VM demonstrated low peak EMG values (<21% of nEMG). However, these followed a comparable EMG-angle pattern as VL and VM of their respective training condition (i.e. using elastic resistance the
EMG increased towards knee extension whereas EMG increased towards knee flexion during the machine exercise). Accordingly, significant differences (p<0.01) were observed in angle at peak EMG between the two exercise conditions.

**External load and contraction time**
The average load of the machine exercise was $28_{\pm}2.31$ kg, ranging from 15-50 kg. The 10 RM elastic resistance ranged from a combination of 1xSilver, 1xBlue and 1xGreen to 3xSilver, 1xBlack, 1xBlue, 1xGreen and 1xRed (TheraBand elastic tubes).

Irrespectively of training condition there was no significant difference in contraction time (i.e. time under tension) during the knee extension exercise. Contraction times for machine and elastic resistance were $1824_{\pm}111$ ms and $1834_{\pm}103$ ms respectively, and for contraction modes concentric vs. eccentric were $1733_{\pm}80$ ms and $1572_{\pm}75$ ms, respectively.

**Perceived loading and influence of age and gender**
Perceived loading assessed with the Borg CR10 rating scale was similar (p=0.67) during knee extensions performed with elastic bands ($5.72_{\pm}0.57$) compared with knee extensions performed in training machine ($5.87_{\pm}0.47$). There were no significant effects of age and gender on muscle activity (p=0.71 and p=0.72, respectively).

**DISCUSSION**
The main finding of this study was that knee extensions performed with elastic tubing induces similar quadriceps EMG muscular activity as knee extensions using an isotonic training machine. However, different EMG-angle patterns existed between exercise conditions.

Irrespectively of loading modality (machine or elastic), there was no significant difference in maximal quadriceps (rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM)) EMG during the concentric contraction phase. The EMG-angle pattern of the VL and VM, however, demonstrated quite a different pattern when comparing the two exercise conditions. When using elastic resistance, the EMG activity of the concentric phase increased from knee flexion position and peaked towards full knee extension whereas a reciprocal behavior was observed during the machine exercise, where the EMG activity increased from extension and peaked closer to knee flexion position. This difference may be explained by the elastic force generation (i.e. external loading) being greatest at the more extended knee angles.
whereas the intramuscular force induced by the external loading may be greater at the more flexed knee angles during the machine exercise.

A recent study by Aboodarda et al. compared the EMG angle-relationship of knee extensions performed using elastic resistance and a Nautilus machine and showed that the average vastus lateralis muscle activity was similar during the two exercise modalities.24 As previously indicated, Aboodarda et al. demonstrated that the applied force exerted during the elastic resistance exercise increases from knee flexion to knee extension, while the Nautilus machine provided a more constant load throughout ROM.24 Although, Aboodarda et al. observed significantly higher exerted forces in the first 66% of ROM

<table>
<thead>
<tr>
<th>Muscle</th>
<th>nEMG (% of max)</th>
<th>Angle at peak EMG (°)</th>
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</thead>
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<tr>
<td></td>
<td>Elastic</td>
<td>Machine</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>SE</td>
</tr>
<tr>
<td>Rectus femoris</td>
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</tr>
<tr>
<td></td>
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<td>53.1</td>
</tr>
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</tr>
<tr>
<td></td>
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</tr>
<tr>
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<tr>
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</tr>
<tr>
<td></td>
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<tr>
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</tr>
<tr>
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</tr>
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<td>Semi tendinosus</td>
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</tr>
<tr>
<td></td>
<td>ECCENTRIC</td>
<td>5.3</td>
</tr>
</tbody>
</table>

Data presented as mean and SE (of the least square means and p-values denotes differences between the elastic and machine exercise.)
(44°-100°) using the Nautilus, the EMG-angle pattern was quite similar (in intensity and shape) displaying an increase towards full knee extension during both exercise modalities. Accordingly, the present EMG-angle pattern using elastic resistance seems comparable with the findings of Aboodarda et al., whereas a reciprocal EMG-angle pattern seems to exist when comparing the Nautilus machine with the machine used in the present study.

Open-chain exercises are generally better tolerated in early rehabilitation of postoperative patients when closed-chain exercises such as a squat are not feasible. Despite conflicting guidelines regarding the impact of patellofemoral stress in extended knee positions studies have shown that open-chain protocols are effective and safe near full knee extension. Accordingly, greater quadriceps muscle activity during extended knee positions, as observed using elastic resistance compared with machines, may be particularly beneficial for rehabilitation of knee pathologies such as ACL injury and following total knee arthroplasty where strength deficits have been observed to be present during the most extended knee angles.37,38 Thus, the observed reciprocal EMG-angle pattern between the two training modalities may have clinical relevance when designing specific rehabilitation and strengthening programmes.

When comparing the two exercise modalities, the RF muscle demonstrated a somewhat similar curvilinear EMG-angle relationship peaking in the mid region (39-55°) of the concentric phase. This similarity in RF EMG-angle pattern between the two types of exercise indicates less dependence on the specific type of regional external loading. This behavior may be explained by the biarticular function of the RF working as a knee extensor as well as a hip flexor consequently leading to enhanced activation in the middle part of range of motion irrespective of exercise modality.

Knee extensions using the isotonic machine resulted in higher eccentric activation values compared to elastic resistance. During the machine exercise the eccentric EMG-pattern was rather constant throughout ROM, whereas the elastic resistance showed an increase in EMG towards knee extension. This may indicate that the higher and more constant eccentric activation during the machine exercise makes this a more effective training modality for rehabilitation of muscular strain injuries.39,40 However, this assertion should be tested in a randomized controlled trial.

An imbalance in the synergetic stabilization ratio of the VM and VL may contribute to knee injuries such as patellofemoral pain syndrome,25,26 Atrophy of the VM is often the cause of an imbalance in the VM to VL ratio,41-43 consequently, making the VM muscle an important target for achieving a balanced knee joint. Thus, exercises with higher VM to VL ratios may be preferred during rehabilitation.23 Nevertheless, in line with previous findings of conventional knee extensions performed in machine the VM:VL-ratio never exceeded 1:00 throughout ROM and was quite similar in the two training modalities. Although none of the exercises seems to preferentially activate VM over the VL, the VM:VL-ratio never fell below 0:85 making both exercises optimal for maintaining patellar joint alignment.

The activation of the non-prime movers (all muscles besides RF, VL and VM) was rather low for both exercise modalities, however, these followed a comparable EMG-angle pattern as VL and VM during their respective training conditions. Accordingly, this indicates that increases in prime mover activity during knee extension are accompanied by a simultaneous increase in synergetic and antagonist muscle activation to preserve fixation and control of the knee and surrounding joints.

Perceived loading was similar between machine and elastic resistance exercises. This is in line with the comparable peak EMG and contraction time (time under tension) values observed during performance of the two exercises. Importantly, the exercises induce high muscle activity regardless of gender and age. Thus, these exercises can be used beneficially for both younger and elderly individuals, as well as men and women.

The knee extension exercise performed with elastic resistance seems to be a feasible and simple method, regardless of age and gender, for achieving high muscle activity potentially stimulating muscular hypertrophy and strength gains in the quadriceps muscles. Its portability makes it ideal for work site training, rehabilitation in hospitals, at home or in training fields where there may be few resources for large training equipment. A
future randomized controlled study is needed to investigate the ability of elastic resistance exercise to increase knee-extension strength over time.

Limitations
The fact that the chair has to be high (or raised), to prevent foot and ground contact when performing the knee extensions using elastic tubing, may limit the feasibility of the exercise. Alternatively, the exercise can be performed with the distal femur elevated e.g. with a pillow or triangular box beneath the thigh to ensure free movement of the lower leg. As this slightly changes the joint angles, it should be noted, that this may alter the muscle activity pattern. However, when considering this suggestion, the difference in hip angle between the elastic and machine exercise (90° vs. 100°) as well as the change in the elastic's angle of pull throughout the ROM should be considered when interpreting the EMG-angle pattern of the two exercise conditions.

CONCLUSION
In untrained individuals, knee extensions performed with elastic tubing induces similar quadriceps EMG muscle activity during the concentric contraction phase, but slightly lower activity during the eccentric contraction phase, as knee extensions using an isometric training machine. During the concentric contraction phase the two modalities displayed reciprocal EMG activity patterns during the range of motion. This reciprocal behaviour may have clinical relevance when designing specific rehabilitation and strengthening programmes.

REFERENCES
16. Andersen LL, Andersen JL, Magnusson SP, Aagaard P. Neuromuscular adaptations to detraining following


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**APPENDIX 1**

**Borg CR10 scale**

Use this scale to rate the load you experience (i.e. weight in the machine or resistance of the elastic band) in relation to your muscle strength.

0 = Nothing at all

10 = The maximal load that you can imagine if you use all your muscle strength

<table>
<thead>
<tr>
<th>Number</th>
<th>Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Nothing at all</td>
</tr>
<tr>
<td>0.3</td>
<td>Just noticeable</td>
</tr>
<tr>
<td>0.5</td>
<td>Very light</td>
</tr>
<tr>
<td>0.7</td>
<td>Light</td>
</tr>
<tr>
<td>1</td>
<td>Light</td>
</tr>
<tr>
<td>1.5</td>
<td>Moderate</td>
</tr>
<tr>
<td>2</td>
<td>Heavy</td>
</tr>
<tr>
<td>2.5</td>
<td>Heavy</td>
</tr>
<tr>
<td>3</td>
<td>Very heavy</td>
</tr>
<tr>
<td>4</td>
<td>Everything</td>
</tr>
<tr>
<td>5</td>
<td>Maximal</td>
</tr>
</tbody>
</table>

*Borg CR10 Scale*
ABSTRACT

**Background:** Rehabilitation programs for patients with patellofemoral dysfunction aim to recruit the vastus medialis obliquus muscle (VMO) in an attempt to reduce pain and to improve patellar tracking.

**Objectives:** The aim of the present study was to use surface EMG to assess the effectiveness of two isometric submaximal contractions (10% and 60% of maximal voluntary contraction, MVC) in promoting preferential activation of VMO over vastus medialis longus (VML) and vastus lateralis (VL) in open and closed kinetic chain isometric exercises with the knee joint fixed at 30, 60 and 90 degrees of flexion.

**Methods and Measures:** Surface electromyography (EMG) signals were recorded with linear adhesive arrays of four electrodes from fourteen healthy young men (age 23.5 ± 3.2, mean ± SD) during isometric knee extension contractions at 10% and 60% of the maximum voluntary contraction (MVC) for 1 min and 20 s respectively at 30, 60 and 90 degrees of knee flexion. Initial values and rate of change (slope) of mean frequency (MNF), average rectified value (ARV) and conduction velocity (CV) of the EMG signal were calculated.

**Results:** Comparisons between the force levels produced at 10% and 60% MVC revealed that the initial values of ARV and CV for the VL, VML and VMO muscle were greater at 60% MVC compared to 10% MVC (3-way ANOVA; F = 536; p < 0.001, F = 49; p < 0.01 for ARV and CV respectively). Comparisons between the different muscles demonstrated lower initial values of CV for VMO compared to VL and VLM at 10% and 60% of MVC (F = 15; p < 0.05). In addition, initial estimates of ARV were higher for VMO compared to VML at both force levels (F = 66; p < 0.05). Comparisons between open and closed kinetic chain exercises revealed higher initial estimates of ARV for open kinetic chain knee extension at both force levels (F = 62; p < 0.01). In addition, the absolute value of MNF slope appeared to increase at higher angles for closed kinetic chain at 60% MVC while it was minimum at 60° degrees for open kinetic chain. No significant differences were observed in the rate of change of CV and MNF among the three muscles.

**Conclusions:** Based on the results of this study, both open and closed kinetic chain exercise similarly activate the three portions of the quadriceps muscle, suggesting that selective training of the vastii muscle is not achievable in these conditions.

**Keywords:** Electromyography, patellofemoral joint, quadriceps, strength training
INTRODUCTION
Patellofemoral Pain Syndrome (PFPS), a generic descriptor for anterior knee pain, is a frequent musculoskeletal complaint among adolescents and young adults related to a large spectrum of patellofemoral joint disorders. In presence of PFPS, athletes typically describe pain in the anterior knee. Pain is related to repetitive high-frequency overload of the joint and is aggravated by uphill and downhill walking/running or prolonged flexing of the knees. Once the patellofemoral joint becomes irritated, secondary subchondral bone degeneration, retinacular nerve injury or persistent aggravation of the peripatellar synovium may occur thus leading to unremitting pain in some subjects.

Physical examination, initially oriented to exclude anterior intraarticular pain, tendinitis and synovitis, may reveal patellofemoral malalignment, tenderness at the patellofemoral facets, pain on patellofemoral compression test, crepitus on extension, giving way, or a positive “J” sign.

Several causes may contribute to the genesis of patellofemoral pain including direct trauma, overuse, and, in particular, malalignment. While opinions vary, the most accepted hypothesis for malalignment is the abnormal lateral tracking of the patella, which may be related to a neuromuscular imbalance between the vastus medialis obliquus (VMO) and vastus lateralis (VL) muscles, leading to a decrease in the activation of the VMO muscle. As a consequence of the abnormal patellar tracking an overload of the retinaculum and of the subchondral bone may arise thus contributing to anterior knee pain. Moreover with knee flexion the medial migration of the patella produces a recurrent stretching of the lateral retinaculum that may cause nerve changes such as neuromas and neural myxoid degeneration.

It is widely accepted that PFPS should be initially managed by non-surgical means and as in most overuse injuries, rest and change of the training schedule may be useful.

Standard physical therapy for patients with PFPS utilizes a multimodal approach including: quadriceps strengthening, aerobic conditioning, quadriceps muscle stretching, kinetic chain balancing, orthotic devices, stretching of the lateral retinaculum, taping, and bracing. Recent authors have suggested that quadriceps muscle deficiency is a major issue in patients with this condition and strengthening of the quadriceps plays an important role in the management of PFPS. Rehabilitation protocols have also included exercises to selectively train the VMO which is normally involved in the tracking control of the patella by balancing the lateral forces imposed by the other vastii muscles and those induced by the physiological valgus of the knee.

The four distinct muscles of the quadriceps, identified on the basis of the anatomical and physiological features, contribute to control the patellofemoral joint. It is generally accepted that among the vastii the vastus medialis can be subdivided into the VMO and the vastus medialis longus (VML) based on the fiber spatial alignment but currently, disagreement exists regarding whether selective activation of VMO over VML and VL is possible.

In fact, over the past decade only few electromyographic studies have demonstrated a higher level of activation of VM than VL muscles during open and closed kinetic chain exercises and no data support the effectiveness of isometric contractions in promoting selective training of VMO. In particular, Cerny demonstrated a higher VM/VL activation ratio during knee extension exercises performed with the subjects in a sitting position with the knee flexed from 30 to 0 degrees (full knee extension was 0 degrees) and the hip maximally medially rotated. A relatively higher activation of VM than VL was also observed at 40 degrees of semisquat with the hip medially rotated 30 degrees and during partial squats with flexion angle from 0 to 50 degrees.

A recent systematic review reported that modifying the lower limb orientation or adding a muscle co-contraction does not preferentially recruit VMO. It included 20 papers with several methodological limitations and no specific information regarding the VMO activation in relation to different knee angles, force levels, and open as well as closed kinetic chain exercise interventions were included.

To date it is not known whether submaximal isometric contractions may be useful to increase the ratio of VMO/VML and VMO/VL activation. Thus, the
aim of the present study was to use surface EMG to assess the effectiveness of two isometric submaximal contractions (10% and 60% of maximal voluntary contraction, MVC) in promoting preferential activation of VMO over VML and VL in open and closed kinetic chain isometric exercises with the knee joint fixed at 30, 60 and 90 degrees of flexion.

MATERIALS AND METHODS

Subjects

Fourteen young healthy male subjects (age 23.5 ± 3.2 years; body mass 80.9 ± 11.5 Kg, height 181.7 ± 6.3 cm) volunteered to participate in the study which was conducted at the Interdepartmental Resource Center of Motor and Sports Activities (CRIAMS) of the University of Pavia, (Voghera, Italy). Prior to participation the subjects received a detailed description of the study and gave written informed consent. Leg dominance was assessed with a physical test. The right leg was dominant in each of the subjects. Subjects, free from neuromuscular or skeletal impairments, were recreationally active in different sports: six in rugby, six in soccer, two in volleyball, one in general fitness. During the 24 hours before each experimental session, subjects were asked to refrain from performing strenuous physical activity. The study conformed with the guidelines in the Declaration of Helsinki and the ethical approval for the study was granted by the Institutional Medical Research Committee.

Procedures

One week before the experimental sessions all the enrolled subjects underwent a session to estimate their isometric MVC at each of the selected angles (30, 60 and 90 degrees of flexion) during two different exercises: an open kinetic chain leg extension (Technogym SpA, Gambettola, Italy) and closed kinetic chain leg press (Technogym SpA, Gambettola, Italy). Both the exercises machines were modified to perform isometric contractions at different selected angles and provide real time feedback on force (MuscleLab 4000e, Boscossystemlab S.p.A., Rome, Italy). Subjects performed three maximum voluntary contractions (MVCs) of 3-5 seconds duration separated by 5 minutes of rest for each of the 6 conditions. Verbal encouragement was provided to the subjects to promote higher forces in each trial. The highest value of force recorded over the three MVCs was selected as the reference MVC, and used to calculate the sub-maximal force targets for 10% and 60% used throughout the study.

Subsequently each subject performed a series of tests divided in two parts, during which surface EMG signals were obtained from the VL, VMO, and VML muscles of the dominant leg during voluntary sub-maximal, isometric muscle contractions. In the first part, using the modified leg extension, subjects performed an isometric contractions of 1 minute duration exerting a force of 10% MVC and 20 seconds exerting a force of 60% MVC (in randomized order) respectively at 30, 60 and 90 degrees of flexion.

In the second part, 1 hour after the end of the first part, subjects performed the same protocol but using the modified leg press. In both parts each test was separated by 10 minutes and continuous verbal encouragement was given during all performance testing. Force signals were recorded with MuscleLab 4000e (Boscossystemlab S.p.A., Rome, Italy). The subject was provided with visual feedback of the force signals in order to maintain 10% and 60% of MVC.

EMG recordings

Single differential surface EMG signals were obtained from the vastii muscles using an adhesive linear array of four electrodes (1 mm wide, 5 mm long, and 10 mm apart, LISiN, Torino - Spes Medica, Battipaglia, Italy). To obtain an optimal placement of the array, EMG signals were detected in a few test contractions during which a non-adhesive array of 16 electrodes was moved over the skin to detect the location of the main innervation zone(s) and tendon regions, as described previously. The orientation of the arrays was selected on the basis of visual signal analysis, choosing the angle of inclination that led to the most similar potentials travelling along the array from the innervation zones to the tendons. The regions where the optimal location for the arrays were identified was treated with abrasive paste. The adhesive arrays were then applied between the innervation zone and distally on the VL, VML, and VMO muscles, following the direction of the muscle fibers. To assure proper electrode-skin contact, 20 μl of conductive paste were spread into the electrode cavities of the arrays with a small spatula. The differential surface EMG signals were amplified (multi-
channel surface EMG amplifier, EMG-USB, LISiN-OT Bioelettronica, Torino, Italy), band-pass filtered (3-dB bandwidth, 10–750 Hz), sampled at 2048 samples/s per channel, A/D converted on 12 bits, displayed online, and stored for further analysis.

**EMG signal analysis**

Surface EMG signals were divided in epochs of 0.5 seconds and variables of interest such as mean spectral frequency (MNF, Hz), average rectified value (ARV, μV) and conduction velocity (CV, m/s) were computed off-line with numerical algorithms. The correlation coefficient between the two adjacent double differential signals was obtained to assess the reliability of CV estimates. For each array of four electrodes, three values of ARV and MNF were obtained for each epoch. The average value of each triplet was utilized for further analysis.

**Statistical analysis**

Linear regression was applied to the data to calculate the initial value and rate of change of MNF, ARV and CV. The linear regression model was shown to fit the experimental data better than the exponential model. This is a common finding for signals obtained during voluntary contractions, particularly for the time course of MNF and CV. Normalized rate of change for each variable was calculated as the percentage ratio between rate of change and initial value. Wilcoxon paired tests were used to compare the initial values of each EMG variable between the two contraction levels. To identify differences in the initial value, rate of change and normalized rate of change between the vastii muscles, a non-parametric analysis of variance (Kruskal–Wallis test) was used, with muscle as the independent factor. Significant differences revealed by the test were followed by the post-hoc Dunn test. Threshold for statistical significance was set to \( p = 0.05 \).

**RESULTS**

Figure 2 shows the initial ARV, MNF and CV estimates for the vastii muscles during submaximal contractions at 10 and 60% of MVC. Table 1 summarizes the chi-square values and the results of the statistical analysis.

![Figure 1](image.png)

**Figure 1.** (A) Schematic representation of the electrode array positions on the vastus lateralis and vastus medialis muscles. The arrays and the main innervation zones are shown. (B) Examples of single differential EMG signals detected with the three arrays from one of the subjects during an isometric contraction at 60% MVC on the leg extension (open kinetic chain) with a knee joint angle of 90 degrees. Grey arrows show the propagation of the motor unit action potentials in the EMG signals and in the picture of the muscle.
In the two sessions, ARV and CV estimates significantly increased with the force level for the three muscles (Kruskal Wallis test; $\chi^2 = 247; p = 0.000002$ and $\chi^2 = 30.2; p = 0.0016$ for ARV and CV respectively) as expected.

Comparisons between the different muscles demonstrated lower initial values of CV for VMO compared to VL and VLM at 10% and 60% of MVC ($\chi^2 = 8.9; p = 0.012$). In addition, initial estimates of ARV were higher for VMO compared to VML at both force levels ($\chi^2 = 39.3; p = 0.0007$) (Figure 2). Comparisons between open and closed kinetic chain exercises revealed higher initial estimates of ARV for open kinetic chain knee extension at both force levels for all muscles ($\chi^2 = 31; p = 0.0012$).

The rate of decrement of MNF increased significantly ($\chi^2 = 15; p = 0.0036$) when angle increased for closed kinetic chain at 60% MVC while it was minimum at 60° degrees for open kinetic chain. No significant differences were observed in the rate of change of CV and MNF for the three muscles ($\chi^2 = 1.7; p = 0.32$ and $\chi^2 = 2.5; p = 0.37$ for ARV and CV respectively) (Table 1, Figure 3).

**DISCUSSION**

The level of muscle activation is represented by the EMG signal amplitude while the rate of change or slope of CV and MNF are indicators of muscle fatigue. Although many factors influence these variables, the analysis within subjects allows to determine if a muscle if more active or more fatigue in one or another condition. Furthermore Rainoldi et al showed, using the same methodological approach as used in the current research, that surface EMG signal can be used to describe myoelectric fatigue and functional differences between the vastii muscles.31

The authors investigated activation and fatigue in vastii muscles at different knee joint angles during

![Figure 2. Initial values of average rectified value (A, B and C), conduction velocity (D, E and F) and mean power frequency (G, H and I) at different knee joint angles (30°, 60° and 90°) respectively. Median, interquartile range and total range are shown for each muscle and each type of exercise at 10% and 60% MVC over the fifteen subjects with box whisker plots. No statistical difference between the muscles was observed in any of the conditions. The three muscles are indicated with different symbols: VL = Δ, VMO = □, VML = ○.](image)
open and closed kinetic chain exercises. The isometric exercises were performed during low and high level of force contraction to optimally observe the vastii activation, while the higher level of force (60% MVC) was also used to examine myoelectric manifestations of fatigue. Results showed that the activation of the three portions of the vastus at the selected angles during both open and closed kinetic chain exercise was not significantly different suggesting that the vastii are similarly active throughout the force ranges studied. Additionally the vastii muscles showed no difference in the myoelectric fatigue during all the exercises that were considered.

### Surface EMG initial estimates

It is well known that increasing the force output would result in progressively higher CV and MNF estimates and this phenomenon stops at different thresholds below MVC depending on the muscle considered and type of contraction it performs. As expected in all
vastii and investigated tasks, comparisons between the two force levels analysed revealed that the initial values of ARV and CV were greater at 60% MVC compared to 10% MVC. On the contrary no changes of the MNF estimates were observed. This evidence may be explained by different responses between CV and MNF during motor unit recruitment.28

Interestingly, during open kinetic and closed kinetic chain submaximal isometric exercises the initial value of ARV was greater for the VMO muscle compared to VL and VML. This evidence is in agreement with previously published data highlighting differences in ARV estimates during sustained isometric knee extension contractions at 60% and 80% MVC.31 The observed changes may possibly reflect inter-muscle differences in the motor neuron pool output.34 Nonetheless discrepancy in the amplitude of surface EMG signals should always be interpreted with caution since they may also be associated with changes in either the shape of the intracellular action potential, volume conductor, sarcolemmal properties of the muscle fibers,34 or differences in subcutaneous tissue thickness.35 In fact, a greater subcutaneous tissue thickness would alter the surface EMG estimates resulting in reduced initial ARV and MNF and elevated CV .35 No data on subcutaneous thickness were collected from the current subjects and the impact of this variable on measured EMG estimates should be a subject for future investigations.

In contrast to ARV, VMO displayed significantly lower initial CV at both force levels in comparison with VML and VL. These differences may be accounted for dissimilar structural and functional features of VMO muscle in comparison with the other vastii. In fact, it is well-known that CV depends on the capacity of voltage-gated sodium channels and Na⁺ - K⁺ pump36 and is positively related to the fiber diameter.37,38 Both these factors may contribute to the observed differences in CV among muscles.

Furthermore, although no data are available on differences in fiber sizes between vastii muscles, the known interrelationship between fiber size, fiber composition and CV should be taken into account.38 In fact, as both CV and fiber type are related to fiber diameter, these parameters could be intercorrelated because both refer to the same variable (i.e., type II fibers present higher values of CV than type I fibers due to their larger diameter).

Therefore, the different fiber types present in the vastii may account for the observed uniformity in CV values. Biopsy studies demonstrated a significant lower proportion of type II fibres in VM muscles in comparison VL19 and, among the VM muscles, a lower proportion of type I fibres in VMO in comparison with VML.19,39,40 Thus, differences in CV values may be explained by diversities in the recruited motor unit pools in which the number of type I fibers with lower CV is higher with respect to type II fibers with higher CV as observed in VMO muscle in comparison with the other vastii. Although this hypothetical explanation is confirmed by the evidence of lower type I and higher type II proportion in VL (higher CV) than in VMO (lower CV), apparently this is not valid for VML. In this muscle a higher CV has been observed despite a higher proportion of type I fibers in comparison with VMO.19 Notwithstanding these concerns at least two issues should be considered. First, available data on muscle composition of the vastii are based on potentially misleading analysis that does not account for the relative proportions of hybrid fibers, containing more than one myosin isoform and thus differently contributing to the overall detectable CV value.19 Second, available data on muscle composition of the vastii has been examined in untrained subjects and it cannot be excluded that an interchange in fiber type composition may arise following selective training in VMO and VML. In particular as endurance training is known to upregulate sodium channels and the Na⁺ - K⁺ pump capacity and to shift the muscle composition towards a higher proportion of slower fiber types in the skeletal muscle41,42 one can speculate that a higher overall endurance of VMO in comparison with VML and VL may also contribute to differences in initial CV values.

Importantly, apart from speculations regarding physiological differences in initial CV values among vastii, is important to highlight that these diversities may be even more pronounced in clinical settings in which non physiological and asymmetric differences in structural and functional features including changes in fiber size and/or muscle composition of the muscles may occur in relation to injury, surgery, or overuse syndromes.
Open versus closed kinetic chain isometric exercise

In all vastii comparisons between open (knee extension) and closed (leg press) kinetic chain exercises revealed higher initial estimates of ARV for open kinetic chain knee extension at both force levels. Such muscle activation during open kinetic chain exercise is in accordance with previous studies and corroborates the idea that overall the open kinetic chain exercises may place higher stress than closed kinetic chain exercises on the patellofemoral joint in the functional range of motion (i.e. during active movements mainly at 35-45 degree angles).

Typically, the ideal ratio between VMO and VL EMG activity (VMO:VL ratio) has been described to be 1:1 and, in presence of patellar dysfunction, this ratio tends to decrease. The imbalance in the synergistic pull of VL and VMO may contribute to patella maltracking and the genesis of anterior knee pain. Researcher have suggested that an appropriate method to counteract patella maltracking is represented by preferential VMO strengthening but controversy still remains on whether isometric submaximal open kinetic chain exercise is to be preferred to closed kinetic chain exercise.

In this study the closed-chain isometric and open-chain knee extension exercise produced equal activation of VMO and VL with unchanged VMO:VL ratio at both force levels analysed. These findings agree with previous observations which also concluded that closed chain kinetic exercises are equally effective than open kinetic chain exercises in promoting VMO activation in isometric conditions.

Rates of change of EMG estimates during isometric submaximal contractions

MNF was shown to shift towards lower frequencies during increasing fatigue. MNF decrease has been attributed to the diminished CV as a consequence of local metabolic changes in the working muscle. However, the modifications of the motor unit (MU) action potential shape, MU firing rate and synchronisation of MUs may contribute to MNF changes as well.

In this study the authors found that during closed kinetic and open kinetic chain exercise the rate of change of MNF increased significantly with increasing angles when muscles were contracted at 60% of the MVC. Interestingly the rate of change appeared minimum for open kinetic exercise at 60° degrees thus identifying this angle as less fatiguing during high activation of the vastii. Finally no significant differences were observed in the rate of change of MNF of the three muscles thus suggesting similar timing of fatigue appearance in VL, VMO and VML during open and closed kinetic chain exercises at 10% and 60% of the MVC at 30, 60 and 90 degrees of knee flexion.

Limitations of the study

The study presents some limitations which should be taken into account before applying the results in the clinical practice. The subject sample was composed only of young healthy men while older patients, females, and especially subjects with PFPS could have different outcomes. Patellar laxity was not evaluated prior to the experiment and this could influence the EMG parameters of the vastii muscles. The composition of muscles was not evaluated with biopsies, thus it was not possible to include considerations of relationship between EMG parameters and fiber types of the vastii muscles.

CONCLUSIONS

The findings of this study indicate that higher initial estimates of ARV for the VMO, VML and VL were found during the open kinetic chain knee extension than during the closed kinetic chain leg press. Furthermore, no preferential activation or myoelectric manifestations of fatigue of VMO over VML and VL (estimated with ARV) is evident during either open or closed kinetic chain submaximal isometric exercises at the force levels analysed (10% and 60% of MVC). Thus, selective training of VMO over VML and VL is not achievable by means of submaximal isometric contractions in the studied conditions.

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ABSTRACT

Background: Quantification of dynamic balance is essential to assess a patient's level of injury or ability to function so that a proper plan of care may commence. In spite of comprehensive utilization of dual-tasking in balance assessment protocols, a lack of sufficient reliability data is apparent.

Purpose: The purpose of the present study was to determine the intra- and inter-session reliability of dynamic balance measures obtained using the Biodex Balance System® (BBS) for a group of athletes who had undergone anterior cruciate ligament reconstruction (ACLR) and a matched control group without ACLR, while using a dual-task paradigm.

Methods: Single-limb postural stability was assessed in 15 athletes who had undergone ACLR and 15 healthy matched controls. The outcome variables included measures of both postural and cognitive performance. For measuring postural performance, the overall stability index (OSI), anterior-posterior stability index (APSI), and medial-lateral stability index (MLSI), were recorded. Cognitive performance was evaluated by measuring error ratio and average reaction time. Subjects faced 4 postural task difficulty levels (platform stabilities of 8 and 6 with eyes open and closed), and 2 cognitive task difficulty levels (with or without auditory Stroop task). During dual task conditions (conditions with Stroop task), error ratio and average reaction time were calculated.

Results: Regarding intrasession reliability, ICC values of test session were higher for MLSI [ACL-R group (0.83-0.95), control group (0.71-0.95)] compared to OSI [ACL-R group (0.80-0.92), control group (0.67-0.95)] and APSI [ACL-R group (0.73-0.90), control group (0.62-0.90)]. Furthermore, ICC values of first test session were higher in reaction time [ACL-R group (0.92-0.95), control group (0.80-0.92)] than error ratio [ACL-R group (0.72-0.86), control group (0.61-0.83)]. ICC values of retest session were higher for MLSI [ACL-R group (0.83-0.94), control group (0.87-0.93)] than OSI [ACL-R group (0.81-0.91), control group (0.83-0.93)] and APSI [ACL-R group (0.73-0.90), control group (0.53-0.90)]. Moreover, ICC values of retest session were higher in reaction time [ACL-R group (0.89-0.98), control group (0.80-0.92)] equated with error ratio [ACL-R group (0.73-0.87), control group (0.57-0.79)].

With respect to inter-session reliability, ICC values were higher for MLSI [ACL-R group (0.72-0.96), control group (0.75-0.92)] than OSI [ACL-R group (0.55-0.91), control group (0.64-0.87)] and APSI [ACL-R group (0.55-0.79), control group (0.46-0.89)]. Additionally, ICC values were higher in reaction time [ACL-R group (0.87-0.95), control group (0.68-0.81)] in contrast to error ratio [ACL-R group (0.42-0.64), control group (0.54-0.74)].

Conclusion: Biodex Balance System® measures of postural stability demonstrated moderate to high reliability in athletes with and without ACLR during dual-tasking. Results of the current study indicated that assessment of postural and cognitive performance in athletes with ACLR may be reliably incorporated into the evaluation of functional activity.

Level of Evidence: 2b

Key words: Anterior cruciate ligament reconstruction, attention, Biodex Balance System®, dual-task paradigm, reliability

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INTRODUCTION
Injuries to the anterior cruciate ligament (ACL) are common in the athletic population.\textsuperscript{1,2} Anterior cruciate ligament reconstruction (ACLR) has been shown to be successful in restoring knee stability and function.\textsuperscript{3} However, the implantation of a substitute for the ACL does not adequately restore the sensorimotor system, which may result in a compromised afferent neural system.\textsuperscript{4} According to multiple authors, a deficient or reconstructed ACL causes biomechanical alterations,\textsuperscript{5,6} as well as decreases in muscular strength\textsuperscript{7,8} and function\textsuperscript{5,9} such as quadriceps inhibition.\textsuperscript{10} Furthermore, knee proprioceptive functions are affected by an ACL reconstruction/deficiency.\textsuperscript{11-15} The ACL provides important sensory information that mediates joint position sense, provides information regarding the threshold for detection of motion, and coordinates muscular reflex stabilization about the knee joint. A deficit in joint position sense, a higher threshold for detection of passive knee motion, and a longer latency of hamstring muscle activation have all been observed in individuals who have sustained an ACL injury and also in those who have undergone reconstruction.\textsuperscript{12} These sensory deficits seem to lead to decreased motor performance. Although decreased static postural control has been reported in ACL-R individuals,\textsuperscript{5,12} dynamic postural control in these individuals has been minimally evaluated.\textsuperscript{4}

Postural stability has been defined as the ability to maintain the center of body mass (COM) over the base of support.\textsuperscript{16} The ability to maintain the COM within the base of support under dynamic conditions is an essential underlying component of physical activity.\textsuperscript{17} Although postural control is traditionally considered to be automatic, therefore requiring minimal information processing, Siu and Woollacott\textsuperscript{18} have shown that the process of maintaining or regaining postural stability requires remarkable information-processing (a cognitive task). The attentional demand needed for regulating postural sway is typically examined using the dual-task paradigm, which presumes that cognitive functions and postural control compete for limited attentional capacity.\textsuperscript{19} Attention is defined as the degree of focus or concentration on a specific task and its capacity is limited. People can only focus on a small number of things at the same time. If the amount of information that needs to be processed by CNS increases, motor performance may be decreased.\textsuperscript{16} Thus, dynamic knee stability may be at greater risk when a given functional task is more complex than during a simpler task. This is because the complexity and attentional demands associated with the complex task are significantly more than during a simple task. It is no surprise that athletes often sustain ACL injuries in complex situations. The role of attention in sensorimotor control, injury, and training has been understudied in the past but currently has begun to receive greater consideration.\textsuperscript{20} Therefore, application of dual-task paradigm in assessment of patients with ACL injuries and reconstructions may be helpful throughout recovery.

Among the devices capable of quantifying measurements of dynamic postural stability, the Biodex Balance System\textsuperscript{®} (BBS) is reported to be able to reliably assess a patient’s neuromuscular control during closed-chain lower extremity tasks.\textsuperscript{19,20} The BBS\textsuperscript{®} uses a circular platform that moves freely in the anterior-posterior (AP) and medial-lateral (ML) axes simultaneously and it has been extensively used to evaluate postural stability in recent years.\textsuperscript{21,22} Although evidence supports importance of assessing the accuracy of balance equipment such as the BBS\textsuperscript{®} for measuring dynamic balance,\textsuperscript{21-23} the reliability of dynamic balance measures provided by the BBS\textsuperscript{®} remains unclear in subjects with and without ACLR with respect to dual-task methodology. Therefore, the purpose of the present study was to determine the intra- and inter-session reliability of dynamic balance measures obtained using the Biodex Balance System\textsuperscript{®} (BBS) for a group of athletes who had undergone ACLR and a matched control group without ACLR, while using a dual-task paradigm.

METHODS
Participants
A total of 30 athletes voluntarily participated in this study. They were matched according to age, sex, height, weight, and level of physical activity (according to Tegner's sport activity level).\textsuperscript{24,25} Fifteen individuals with ACLR (mean time since surgery 12 ± 6 months) were recruited. The ACLR group included 1 female and 14 males with a mean age of 26.00 ± 7.31 years, height of 174.58 ± 5.84 cm, weight of 80.24 ± 10.61 kg, and the Tegner activity score of 5.74 ± 2.51. The matched control group included 1 female and 14 males of mean age 23.37 ± 6.50 years,
height 172.69 ± 5.37 cm, weight 77.87 ± 9.46 kg, and the Tegner activity score 6.58 ± 1.93.

All ACLR surgeries were performed in a similar fashion (arthroscopically assisted anatomic double-bundle anterior cruciate ligament reconstruction using autogenous hamstring tendons). Subjects in the ACLR group were pain free, full weight bearing, functionally stable, had normal gait at the time of study, and were cleared by the orthopedic surgeon for participation in this study. Healthy athletes who reported no history of any substantial orthopedic injury or balance-related disorders served as the control group. Substantial orthopedic injury was defined as an injury with symptoms persisting for longer than 2 weeks.

Both control and ACLR individuals were excluded if they had any balance, vestibular or visual problems, or a significant injury to either lower extremity other than the ACL rupture or if they had injured any other knee ligaments at the time of the ACL rupture over the last year. Individuals who had undergone minor non-surgical meniscal treatment, whose pain and other symptoms with utilization of anti-inflammatory medications and cold packs applied to the knee ceased within two or three weeks after injury, were included. The side tested for those in the control group was matched to the involved side of those in the ACLR group. Subjects were briefed on all testing procedures and asked to read and sign a consent form approved by Ethics Committee of the University of Social Welfare and Rehabilitation Sciences. Also, subjects completed a questionnaire before being tested, through which the exclusion criteria were reviewed.

Postural Task

The Biodex Balance System® (BBS) (Biodex Medical Systems, Shirley, NY) was used to assess postural performance. The BBS® is a multiaxial device that objectively measures and records the ability of individual to maintain posture under dynamic stress. Unlike force plate systems, the BBS® uses a circular platform, which is free to move in the anterior–posterior and medial–lateral directions simultaneously.21 The BBS® calculates a medial–lateral stability index (MLSI), an anterior–posterior stability index (APSI), and an overall stability index (OSI). These indices are variances of displacement measures and represent fluctuations around a zero point established prior to testing when the platform is stable.21 The BBS® software samples the degree of tilt from level in the medial-lateral (X) and anterior-posterior (Y) directions at a frequency of 20 Hz.21 Stability scores were calculated by the BBS® computer interface and then manually copied and entered into a statistical software package (SPSS, Version 15).

Higher scores on the stability indices indicate a greater amount of postural variability, hence decreased postural stability. The difficulty of the postural stability task can be varied from stability level 8 to stability level 1. Level 8, which is the highest level of stability, allows the platform to be least easily tilted and therefore makes it easier for subjects to maintain stability. Level 1, which is the lowest level of stability, allows the platform to be most easily tilted and makes it more difficult for subjects to maintain stability.16 It is possible to adjust the stability of the system by changing the resistance force applied by springs to the underside of the platform.28 So, the lower the stability level (resistance force) the less stable the platform.22

In the present study, the subjects were tested at two Biodex® stability levels: levels 8 and 6, based upon a pilot study conducted by the authors. The results of this preliminary study demonstrated that the ACLR participants were typically unable to complete the test at lower levels of stability when standing on their affected limb (stability level settings lower than 6). Participants were asked to stand on the involved limb (or in the case of the controls, the limb matched to the ACLR limb of their paired subject) on the BBS® platform with their eyes open and then closed for 30 seconds during each trial. During eyes open conditions, the participants were asked to look straight at a small piece of paper on the wall at their eye level.27 During eyes closed conditions, participants were asked to look straight at a small piece of paper on the wall at their eye level.27

During eyes closed conditions, participants wore a blindfold to eliminate visual feedback. The unsupported foot was placed behind the weight-bearing ankle during testing (Figure 1). Participants stood barefoot with both hands placed upon the iliac crests. Next, participants were instructed to adjust the position of the supporting foot until they found a position where they were able to maintain platform stability. The platform was then locked and the subject's foot position coordinates were marked on the platform as an array of (X, Y) coordinates and recorded by the
The angle of the third metatarsal in reference to the Y-axis was also recorded manually. The subjects were instructed not to move their test foot from the platform throughout test trials as the examiner altered the experimental conditions between difficulty levels. Subjects repeated the trial if they put their non-weightbearing foot down or if they touched the handrails with their arms during the test.

Cognitive Task
An auditory version of the Stroop task was used. In this task, the subjects were presented the Persian equivalents of the words “high” and “low” in either a high or low tone pitch. The participant was asked to verbally respond with the word which was reversely correspondent to the heard pitch as quickly and accurately as possible, regardless of the word meaning, during a 30 second trial. Congruency between pitch and the word was randomized. Error ratio (number of errors/number of auditory signals) and the average reaction time were recorded during each trial.

Verbal reaction times (VRT) during Stroop tasks were calculated from the time difference between auditory stimulus onset and the onset of the verbal response. The program used during the auditory Stroop task was written by a programmer and implemented by Matlab® (R2010A, Mathworks, Navick, MA, USA) software, with stimuli relayed via a wireless headset (SHB6111, Koninklijke Philips Electronics NV, China). Verbal responses to the auditory stimuli were recorded through a wireless microphone (NP-101, LEM, Taiwan). The response time of each word was recorded by Matlab® software in the Microsoft Office Excel 2007. Then, data were analyzed using SPSS Version 15. Words were presented for 500 ms, and the subjects were asked to answer as quickly as possible. The interval between the two consecutive stimuli was randomized (2,000 ms to 3,000 ms), so that participants could not anticipate the initiation of stimuli. All reactions with response delays longer than 3,500 ms were discarded, because they exceeded the interval time between the two stimuli.

Experimental Procedures
Dual-task methodology is a testing model that necessitates a person to carry out two tasks concurrently. In order to assess dual-task interference, the most current approach is to compare dual-task performance in both postural and cognitive tasks against their baseline performance, and to investigate interference by examining interactions between dual-task components.

In the present study, 4 levels of postural difficulty (level 6 with eyes-open, level 6 with eyes-closed, level 8 with eyes-open, and level 8 with eyes-closed) were combined with 2 levels of cognitive difficulty (with and without cognitive task). Therefore, each subject completed 8 experimental conditions. In no-cognitive (single task) condition, participants were instructed to maintain the platform stable for a 30-second data collection period. For dual-task conditions, participants performed the cognitive task while attempting to maintain postural stability. Experimental condition combinations (stability level, eyes open/closed, cognitive difficulty) were randomized for each subject. During the first (test) session, each condition within the 8 randomized conditions was repeated four times, with one minute rest between trials to measure intra-session reliability. Then the second (retest) session was presented with the same protocol three to five days later.
For the sake of familiarization, auditory Stroop and dynamic postural tasks were practiced three times by the participants. The entire experiment lasted approximately 120 minutes for each subject. To assess intersession reliability of the BBS® measures, the subjects were retested in a separate session 3 to 5 days later. The order of testing conditions in both sessions was randomized but the other test situations were similar. Therefore, standardized testing conditions were used to estimate the test-retest reliability.

**Data Analysis**

Paired t-tests were used to compare the differences between stability scores in test and retest sessions in order to explore the presence or absence of any systematic bias. For the intra-session reliability of stability indices, reaction times, and error ratios, the 4 trials of each condition were used to calculate reliability. For the test-retest reliability, the 4 trials for each condition were averaged (in session 1 and session 2).

Relative intra- and inter-session reliabilities were calculated using a 2-way random model of intraclass correlation coefficient (ICC2,4) described by Shrout and Fleiss. Munro's classification for reliability coefficients was utilized to determine the extent of reliability. According to this classification, criteria ranges for reliability are as follows: 0.00 to 0.25- little, if any correlation; 0.26 to 0.49- low correlation; 0.50 to 0.69- moderate correlation; 0.70 to 0.89- high correlation and 0.90 to 1.00- very high correlation. In order to assess absolute reliability, the standard error of measurement (SEM = the square-root of the mean-square error term) and 95% confidence intervals (CI) were computed to make an estimate of the amount of error associated with the measurement in the same units as the measurement. To assess the change that could be considered clinically significant between two times of measurement, the minimal detectable change (MDC) was determined as 95% CI of SEM of a stability index measure (1.96 SEM). Moreover, the coefficient of ariation (CV) was settled for pointing out of similarities and differences of absolute reliability between stability indices ([SD/mean] × 100). All significance levels were set at p < 0.05.

**RESULTS**

There was no statistically significant difference in age (p = 0.82), weight (p = 0.53), height (p = 0.97), Tegner's sport activity level (p = 0.46), and sex distribution (p = 0.76) between the two groups. Table 1 and 2 represent mean scores and standard deviations of Biodex® stability measures, reaction times and error ratios for all testing conditions. Also, there was no significant difference between test and retest mean scores for the above-mentioned parameters, which demonstrates no systematic bias (p > 0.05).

In general, moderate to high levels of reliability for postural performance, measures in ACLR and control groups respectively, were found. The intrasession ICCs of initial test session ranged from 0.80 to 0.92 (ACLR) and 0.67 to 0.95 (controls), ICCs of retest session ranged from 0.81 to 0.91 and 0.83 to 0.93, and intersession ICCs ranged from 0.55 to 0.91 and 0.64 to 0.87 for OSI. Intrasession ICCs of initial test session ranged from 0.73 to 0.90 (ACLR) and 0.62 to 0.90 (controls), ICCs of retest session ranged from 0.73 to 0.90 and 0.53 to 0.90, and intersession ICCs ranged from 0.55 to 0.79 and 0.46 to 0.89 for APSI. Intrasession ICCs of initial test session ranged from 0.83 to 0.95 (ACLR) and 0.71 to 0.95 (controls), ICCs of retest session ranged from 0.83 to 0.94 and 0.87 to 0.93, and intersession ICCs ranged from 0.72 to 0.96 and 0.75 to 0.92 for MLSI.

The ranges of SEM for postural performance, in ACLR and control groups respectively, were from 0.46 to 1.25 and 0.31 to 0.70 for OSI, from 0.19 to 1.09 and 0.26 to 0.65 for APSI, and from 0.22 to 0.94 and 0.19 to 0.46 for MLSI.

The ranges of CV for postural performance, in ACLR and control groups respectively, were from 20.82% to 49.79% and 20.94% to 29.39% for OSI, from 19.55% to 40.69% and 18.89% to 30.26% for APSI, and from 15.52% to 37.27% and 27.10% to 37.33% for MLSI.

Finally, the ranges of MDC values for postural performance, in ACLR and control groups respectively, were from 0.90 to 2.45 and 0.61 to 1.37 for OSI, from 0.37 to 2.14 and 0.51 to 1.27 for APSI, and from 0.43 to 1.84 and 0.37 to 0.90 for MLSI (Table 3).

It is notable that a moderate to high level of reliability for cognitive performance in ACLR and control groups respectively was also displayed, with ICCs of initial test session for reaction time ranging from 0.92 to 0.95 (ACLR) and 0.80 to 0.92 (controls), ICCs of the retest session ranged from 0.89 to 0.98 and...
The range of SEM for cognitive performance, in ACLR and control groups respectively, was from 0.12 to 0.18 and 0.07 to 0.13 for reaction time (milliseconds), and from 0.11 to 0.15 and 0.05 to 0.11 for error ratio. Moreover, the range of CV for cognitive performance, in ACLR and control groups respectively, was from 41.11% to 51.14% and 20.00% to 31.25% for reaction time, and from 70.00% to 79.00% and 11.11% to 78.18% for error ratio. Finally, the range of MDC values for cognitive performance, in ACLR and control groups respectively, was from 0.24 to 0.32 and 0.16 to 0.20.

Furthermore, the range of SEM for cognitive performance, in ACLR and control groups respectively, was from 0.12 to 0.18 and 0.07 to 0.13 for reaction time (milliseconds), and from 0.11 to 0.15 and 0.05 to 0.11 for error ratio. Moreover, the range of CV for cognitive performance, in ACLR and control groups respectively, was from 41.11% to 51.14% and 20.00% to 31.25% for reaction time, and from 70.00% to 79.00% and 11.11% to 78.18% for error ratio. Finally, the range of MDC values for cognitive performance, in ACLR and control groups respectively, was from 0.24 to 0.32 and 0.16 to 0.20.
to 0.35 and 0.14 to 0.25 for reaction time, and from 0.22 to 0.29 and 0.10 to 0.22 for error ratio (Table 4).

**DISCUSSION**

The present study examined the inter-session and intra-session reliability of the BBS® in subjects with and without ACLR during dual-task performance. To the authors' knowledge, there has been no study to date on the reliability of BBS® measurements in subjects with and without ACLR using a dual-task methodology. BBS® postural stability measures were reliable and may be useful for measuring the postural balance and monitoring programs for improvement of postural control in ACLR knees. However, there is no evidence about the validity of BBS® measures and to the authors knowledge, it has not been evaluated in any related article.

The results of this study suggest that ICC values were higher for MLSI compared to OSI and APSI for different conditions of postural and cognitive task difficulty. Additionally, ICC values were higher for reaction times in comparison with error ratios in all tested conditions. Generally, the results showed a moderate to high level of reliability for the measurements of stability indices and cognitive outputs in thorough trials.

Hinman26 determined higher reliability of BBS® measures in elderly when more challenging postural

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**Table 3. Intra- and Intersession Reliability of the Biodex Stability System Measures Made under Different Conditions of Postural and Cognitive Difficulty in a Sample of Individuals with ACLR (n = 15) and Healthy subjects (n = 15). [ICC, intraclass correlation coefficient; SEM, standard error of measurement; MDC, minimal detectable change]**

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<td>3.13%</td>
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<td>2.22%</td>
<td>0.89</td>
<td>0.92</td>
<td>0.86</td>
<td>0.55</td>
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</table>
conditions were displayed which is consistent with the current findings. Single-limb stance on a movable platform with eyes closed during dual-tasking may be at a level of difficulty that might lead to greater variability of balance performance among subjects with ACLR. Thus, this condition would likely result in higher ICC values than those in healthy subjects in most testing conditions. However, in the study of Hinman et al,26 the balance test duration was exactly the same as the current protocol (30 seconds). However, their test and retest sessions were performed on the same day with an interval of 30-60 seconds. Moreover, Hinman26 developed the test with subjects wearing hard- or soft-soled shoes while in the current study the participants were asked to stand barefoot on the Biodex platform. In the current protocol, the time between evaluation times was different (3 to 5 days) and two different levels of stability on the BBS® were employed, Level 8 (the same stability level used in the study of Baldwin et al.37 and Level 6. Furthermore, Hinman26 only analyzed the relative reliability but not absolute reliability as recommended by recent studies.38,39

Generally speaking, reliability measures achieved in this study for all stability indices (Table 2) were higher than those reported by Pincivero et al23 and lower than those of Cachupe et al22 in single task conditions. Also, in single task conditions, the current SEMs, similar to those of Parraca et al,39 were better than those in the previous studies.22 Use of different test protocols among studies, makes it impossible to directly compare their results.

There is little evidence with respect to the reliability of auditory Stroop task.40 Relative and absolute reliability with correlation coefficients ranging from 0.84 to 0.94, and SEMs ranging 0.047 to 0.219 were reported by Jerger et al.40 These values were calculated for reaction time task in five different conditions of the auditory Stroop test in normal children. The observed differences between current reliability results and the latter study could be explained by the different target populations and the varied auditory Stroop tasks.

The most important characteristic of the ICC is its sensitivity to between-subject variability.33 In the immediate surroundings of high between-subject variability, a large ICC can be achieved even if the absolute reliability is low.33 The SEM, an estimate of error for interpreting an individual’s test score, is directly related to the reliability of a test; that is, the larger the SEM, the lower the reliability of the test and the less precision in the scores obtained. The CV expresses the standard deviation as a percentage of the sample mean which allows comparison of variability estimates eliminating the effect of mean values.34 The estimated MDC of each stability index measure provides information

### Table 4. Intra- and Intersession Reliability of the Cognitive Test Measures Made under Different Conditions of Postural and Cognitive Difficulty in a Sample of Individuals with ACLR (n = 15) and Healthy subjects (n = 15).

<table>
<thead>
<tr>
<th>Level</th>
<th>Task</th>
<th>Cognitive Test</th>
<th>ACL-R Group</th>
<th>Healthy Group</th>
</tr>
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<tr>
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<td>Intrasession ICC</td>
<td>Retest ICC</td>
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<td>8</td>
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<tr>
<td></td>
<td></td>
<td>Error Ratio</td>
<td>0.72</td>
<td>0.87</td>
</tr>
<tr>
<td>Closed</td>
<td></td>
<td>Reaction Time</td>
<td>0.93</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error Ratio</td>
<td>0.88</td>
<td>0.84</td>
</tr>
<tr>
<td>Open</td>
<td>6</td>
<td>Reaction Time</td>
<td>0.95</td>
<td>0.98</td>
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<tr>
<td></td>
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<td>0.81</td>
<td>0.84</td>
</tr>
<tr>
<td>Closed</td>
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<td>Reaction Time</td>
<td>0.93</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error Ratio</td>
<td>0.82</td>
<td>0.73</td>
</tr>
</tbody>
</table>
about the amount of measurement error that should be taken into account when setting the least significant changes expected following two consecutive measurements.36,41 The current reliability results could not be generalized to other athletes’ populations and other dynamic and static postural conditions. However, the results of this research may act as a basis for improving the reliability of the evaluation of balance in patients with ACL reconstructed knees, and better describing the deficit(s) discovered in balance especially during dual-tasking. Dual-task training may have benefits over single-task training if the purpose of practice is to enhance postural control performance. However, this assertion requires further investigation in future.

To extend the work completed in the present study, future researchers might investigate (a) the reliability of BBS® measures among groups of varying history of injury, activity levels, and functional capacity; (b) the reliability of BBS® measures among athletes who participate in different sports; (c) the reliability of BBS® measures at different levels of platform stability and for different length trials; (d) the reliability of BBS® measures during different cognitive demands.

CONCLUSIONS

Biodex® measures of postural stability, as well as reaction times and error ratios during the auditory Stroop task have been found to be reliable during testing of a single-leg postural control protocol, utilizing multiple test constructs, both within a single session and between sessions. Therefore, these procedures may be recommended for obtaining reliable measures of dynamic postural assessment in ACL reconstructed athletes, especially in dual-task conditions.

REFERENCES

17. Park WH, Kim DK, Yoo JC, et al. Correlation between dynamic postural stability and muscle


ABSTRACT

Background/Purpose: Frontal plane running mechanics may contribute to the etiology or exacerbation of common running related injuries. Hip strengthening alone may not change frontal plane hip and knee joint running mechanics. The purpose of the current study was to evaluate whether a training program including visual, verbal, and tactile feedback affects hip and knee joint frontal plane running mechanics among females with evidence of altered weight bearing kinematics.

Methods: The knee frontal plane projection angle of 69 apparently healthy females was determined during a single leg squat. The twenty females from this larger sample who exhibited the most acute frontal plane projection angle (medial knee position) during this activity were chosen to participate in this study (age = 20 ± 1.6 years, height = 167.9 ± 6.0 cm, mass = 63.2 ± 8.3 kg, Tegner Activity Rating mode = 7.0). Participants engaged in a 4-week movement training program using guided practice during weight bearing exercises with visual, verbal, and tactile feedback regarding lower extremity alignment. Paired t-tests were used to compare frontal plane knee and hip joint angles and moments before and after the training program.

Results: After training, internal hip and knee abduction moments during running decreased by 23% ($P = 0.007$) and 29% ($P = 0.033$) respectively. Knee adduction and abduction excursion decreased by 2.1° ($P = 0.050$) and 2.7° ($P = 0.008$) respectively, suggesting that less frontal plane movement of the knee occurred during running after training. Peak knee abduction angle decreased 1.8° after training ($P = 0.051$) although this was not statistically significant. Contralateral peak pelvic drop, pelvic drop excursion, peak hip adduction angle, hip adduction excursion, and peak knee adduction angle were unchanged following training.

Conclusions: A four week movement training program may reduce frontal plane hip and knee joint mechanics thought to contribute to the etiology and exacerbation of some running related injuries.

Level of Evidence: Level 4

Keywords: female, kinematics, kinetics, neuromuscular training, rehabilitation
INTRODUCTION

The benefits of regular exercise are widely described and may lead people to engage in activities such as running. It is estimated that over 35 million Americans use running as a mode of regular physical activity. However, 19-79% of these runners may experience an injury each year. Altered frontal plane hip and knee joint mechanics during the stance phase of running may contribute to the etiology of many common running injuries. For example, increased hip adduction angle, internal hip abduction moment, and internal knee abduction angular impulse have been reported among runners with patellofemoral pain. Additionally, high peak hip adduction angles during running may increase a runner’s risk of developing tibial stress fractures and iliotibial band syndrome. Clinically-oriented interventions to reduce these altered frontal plane running kinetics and kinematics may be valuable for rehabilitation of such individuals who sustain these running related injuries.

Hip muscle strength appears to have little association with altered frontal plane running mechanics. Focused training studies to increase hip abduction and external rotation strength have not decreased hip or knee frontal plane peak joint angles or joint excursions during the stance phase of running. Further, a low correlation has been reported between hip strength and frontal plane hip and knee peak angles and joint motions during running and jumping. The clinical relevance of these studies is that hip strengthening alone may not be an effective remedy for altered lower extremity running mechanics that may increase the risk of running related injury.

It may be necessary for clinical interventions to incorporate elements intended to affect neuromuscular control of muscles that may diminish altered frontal plane running mechanics. Such elements may include guided practice using visual, verbal, or tactile feedback of movement performance. For example, females with patellofemoral pain (PFP) demonstrated significantly less peak hip adduction while running at the end of a 2-week training program where participants were provided visual feedback of three-dimensional hip kinematics during running. Additionally, a 14-week rehabilitation program for PFP that included visual feedback and hip strengthening exercises was also found to decrease pain and hip adduction angle for an individual with PFP during a single leg step down. Finally, peak hip adduction and knee abduction angles during a drop jump activity decreased among subjects who received visual feedback for altering movement performance and strength training.

A home-based training program to reduce hip and knee joint frontal plane motion and peak moments may be of value to clinicians seeking to improve altered running mechanics observed in their patients. Based on the available evidence, it seems such a program should emphasize neuromuscular control elements such as guided practice of movement performance and visual, verbal, and tactile feedback rather than hip strengthening alone. Unfortunately, the authors are aware of only a single previous study that has emphasized visual and verbal feedback in a home-based exercise program with the goal of improving running mechanics. This study reported that peak hip adduction angle and contralateral pelvic drop did not change at the conclusion of a six-week program that included four weeks of visual and verbal feedback during weight bearing exercises traditionally used for hip strengthening. However, changes in knee joint mechanics were not included in the results of their study. Therefore, the purpose of the current study was to evaluate whether a training program including visual, verbal, and tactile feedback affects hip and knee joint frontal plane running mechanics among females with evidence of altered weight bearing kinematics. The authors hypothesized that after training, the participants would demonstrate decreased frontal plane hip and knee joint peak angles, excursion, and moments during running.

METHODS

Subjects:

Using $\alpha = 0.05$, $\beta = 0.2$, and a recent estimate of hip and knee joint frontal plane kinematic variability during running, we determined that 18 subjects were necessary to identify changes in frontal plane running kinematics of greater than 2.8° after training (effect size $>0.7$). A more medial knee position during weight bearing activities has been associated with both acute and chronic knee injuries.
Thus, the authors aimed to enroll females who clearly demonstrated this movement characteristic during a single leg squat as they may have been more likely to demonstrate altered running kinematics, experience overuse knee injuries, and therefore benefit from a structured neuromuscular training program intended to change altered weight-bearing mechanics (prior to or after injury). To find these 18 females, the authors screened 69 active and apparently healthy females with an age range of 18-25 years who were recruited from a university population. No potential subject had a history of chronic or accidental injury over the last 6 months. Each subject was a regular participant in weight-bearing exercises that may have included recreational sports, cardiovascular training, or weight training at least 3 times/week for ≥30 min. Exclusion criteria included reports of lower extremity injury within the last 3 months requiring medical treatment, history of lower extremity surgery within the last 12 months, or pain or restriction with running, jumping, or stair negotiation. Appropriate ethical approval had been granted from an institutional review board prior to the commencement of the study and all participants provided their informed consent prior to participation.

Two-Dimensional (2D) Analysis:
To determine which subjects demonstrated the greatest medial knee position during a single leg squat, 2D medial knee position was recorded with a digital camera (Samsung model L200, Samsung Electronics, Ridgefield, NJ USA) for all 69 female volunteers during a step-down task using a 20.3 cm step. This measurement has been described as frontal plane projection angle (FPPA). The camera was leveled and placed on a tripod at a height of 70 cm from the floor, 7.6 m to the front and perpendicular to the 20.3 cm step. Each participant wore the same shoe model (Running shoe model 629, New Balance Boston, MA, USA) to avoid variability in different sole materials between subjects and testing sessions. Two millimeter adhesive markers were placed only on the dominant leg (preferred leg used to kick a ball as far as possible). A tape measure was used to bisect the ankle malleoli and femoral condyles. Markers were placed at these identified midpoint locations. The tape was then used to form a line from the anterior superior iliac spine (ASIS) to the knee joint marker and a marker was placed on this line approximately 30 cm above the knee marker. Next, subjects were provided both a demonstration and verbal instruction of the step down without specific directions regarding knee and hip alignment. Each step down was to be completed over a 5-s interval from descent to ascent paced by a digital metronome (Qt 3 Digital Metronome, Model 96204X, Mel Bay Publications Pacific, MO) set at a rate of 60 beats/minute. The initiation of the step down occurred at 1 s (beat 1), lowering their non-stance leg until their heel lightly touched the floor in front of the step at 3 s (beat 3), and finishing in a standing position at 5 s (beat 5). A digital picture was taken at the second metronome beat during each performance trial. After demonstrating adequate skill, subjects performed 5 trials for analysis. There was a 60 second rest period between practice trials and the 5 test trials. The FPPA was calculated by measuring the angle formed by lines drawn on the image between the thigh and knee markers and between the ankle and knee markers (CorelDraw v11.6, Corel Corporation, Ottawa, Ontario, Canada) (Fig 1). Average FPPA value from the 5 trials was calculated for each subject. Knee markers medial to thigh and ankle markers were assigned negative FPPA values while knee markers in a lateral position were assigned positive FPPA values. Of the original 69 volunteers, 20 subjects with the most acute negative FPPA values were invited to participate in the training program [FPPA = −8.5° (range = −4.5° to −15.3°, sd = 2.6°), age = 20.0 yr (sd = 1.6 yr), height = 167.9 cm (sd = 6.0 cm), mass = 63.2 kg (sd = 8.3 kg), Tegner Activity Rating mode = 7.0 (range = 5–9)]. The FPPA measured among these 20 participants was consistent with the FPPA reported among female runners with patellofemoral pain in a previous study. Twenty subjects were chosen to account for the possibility of dropouts associated with the nature of the training portion of this investigation. Eighteen of these 20 subjects participated in all phases of the study and were included in the statistical analysis (Fig. 2).

Three Dimensional (3D) analysis of running mechanics:
Lower extremity mechanics were recorded as subjects ran along a 23 meter runway. Specifically, reflective tracking markers were placed on the right and left ASIS, the sacrum, the right and left posterior
superior iliac spine, the anterior thigh, the lateral femoral condyle, the tibial tuberosity, anterior shank along the tibial plateau, the lateral malleolus, and the dorsum of the foot, heel, and superior surface of the 2nd metatarsal of each subject’s shoe. Temporary markers on the medial femoral condyle and medial malleolus were also used to mark the segment endpoints, which were removed prior to running trials. The 3D marker coordinate data were captured at 240 Hz using an 8 camera motion analysis system (Motion Analysis Corporation, Santa Rosa, CA, USA). These data were smoothed at 12 Hz using a 4th order recursive Butterworth low pass filter. Hip and knee joint kinematics were calculated from the local coordinate data using Motion Monitor Software (Version 7.0, Innovative Sports Training, Chicago, IL, USA). The subjects were asked to run between 3.52 and 3.89 m/s as indicated by feedback from the investigator immediately after each trial regarding the average forward velocity of the sacral marker over the last 9 video frames of terminal swing prior to contact with the force platform. Ground reaction forces were recorded at 1080 Hz by a force platform (Model 4080, Bertec Corporation, Columbus, OH, USA) flush with the surface of the runway. These analog data were filtered at the same cutoff frequency as the kinematic data. The inverse dynamics approach was used to calculate frontal plane hip and knee internal joint moments. Each subject completed five practice trials, followed by five trials collected for use in data analysis. The average peak value for these kinematic and kinetic variables during the five trials were determined for the stance phase of the running cycle.

**Neuromuscular Training:**
Subjects participated in a 4-week movement training program using exercises adopted from previous training programs with an emphasis on gluteus medius

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**Figure 1.** Markers used to determine the frontal plane projection angle (FPPA) during single leg step downs.

**Figure 2.** Flowchart of subject progression in this pre-test, post test quasi-experimental design.
and gluteus maximus facilitation techniques believed to influence lower extremity alignment and foster hip and knee joint neuromuscular control (Table 1). To isolate the neuromuscular effects of the intervention, the training program in this study was limited to 4 weeks to limit the potential influence of hypertrophic muscle changes on running mechanics. Subjects received personal instruction and verbal and visual (using a mirror) feedback during movement performance of all exercises one time/week. Instructions provided to participants included keeping the knee in line with the hip and foot in the frontal plane, the pelvis parallel with the floor, and to increase hip flexion to avoid anterior motion of the knee beyond the foot during squat exercise performance. Single-leg exercises were performed on dominant leg only. All exercises were performed independently at home an additional two times/week with use of a mirror.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Volume</th>
<th>Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall or form squat</td>
<td>3 x 10 reps</td>
<td>Bend knees to 90°, hold 5 seconds</td>
</tr>
<tr>
<td>Forward lunge</td>
<td>3 x 10 reps</td>
<td>Step forward with dominant leg and bend knees to 90°</td>
</tr>
<tr>
<td>Lateral step-down 4” step</td>
<td>3 x 10 reps</td>
<td>Stand on step, lower non-dominant foot to floor but do not touch the floor</td>
</tr>
<tr>
<td>Single-leg stance with ball toss</td>
<td></td>
<td>Knee slightly bent, throw ball forward against a wall or to a partner</td>
</tr>
<tr>
<td>Lateral step-down 7” step</td>
<td>3 x 10 reps</td>
<td>Stand on step, lower non-dominant foot to floor but do not touch the floor</td>
</tr>
<tr>
<td>Forward step-up 7” step</td>
<td>3 x 10 reps</td>
<td>Facing step, raise up onto dominant leg, lower non-dominant heel back to floor</td>
</tr>
<tr>
<td>Single-leg deadlift</td>
<td>3 x 10 reps</td>
<td>Knee slightly bent, touch floor in front of foot with both hands</td>
</tr>
<tr>
<td>Lateral shuffles with theraband</td>
<td>3 x 40 ft</td>
<td>Elastic around and above both knees, walk laterally with knees slightly flexed</td>
</tr>
<tr>
<td>Forward step-down 7” step</td>
<td>3 x 10 reps</td>
<td>Stand on step, lower non-dominant foot to floor but do not touch the floor</td>
</tr>
<tr>
<td>Balance lunge</td>
<td>3 x 10 reps</td>
<td>With non-dominant leg on chair behind you, step forward and flex knee to 90°</td>
</tr>
<tr>
<td>Single-leg multidirectional reach</td>
<td>3 x 5 reps</td>
<td>Knee slightly bent, touch floor in front of foot with both hands. Repeat to locations on floor at 45° medially and laterally</td>
</tr>
<tr>
<td>Single-leg squat with theraband</td>
<td>3 x 10 reps</td>
<td>Elastic around and above both knees, stand on dominant leg and bend knee to 60°. Contralateral knee is flexed and hip is maintained in slight abduction.</td>
</tr>
</tbody>
</table>
Statistics:
Ten paired samples t-statistics ($\alpha = 0.05$) were used to compare pelvis, hip, and knee peak frontal plane angles and excursion (frontal plane motion from initial contact to peak angle during the stance phase) and peak hip and knee internal joint moments before and after the movement training program. Effect sizes were calculated to illustrate the magnitude of change in these variables. All statistical procedures were performed in SPSS (version 17, SPSS Inc., Chicago, IL).

RESULTS
Eighteen of 20 subjects completed all phases of the study including movement training and post-testing. According to exercise logs kept by each subject, there was 100% compliance in exercise performance three times/week, and 85% compliance in using a mirror to provide visual feedback on lower extremity alignment when performing the exercises.

Following the four week movement training program there were notable changes in hip and knee frontal plane moments. Specifically, internal hip and knee abduction moments decreased by 23% (effect size = 0.74, $P = 0.007$), and 29% (effect size = 0.71, $P = 0.033$), respectively (Figure 3, Table 2). After training, participants also tended to demonstrate a more lateral position of the knee during running as evidenced by a 1.8° decrease in peak knee abduction angle (effect size = 0.50, $P = 0.051$), a

Figure 3. Time normalized hip and knee angles and internal joint moments during the stance phase of running among participants before and after the 4 week movement training intervention. The shaded regions represent 1 standard error of the mean at each time point.
2.1° increase in knee adduction excursion (effect size = 0.51, \( P = 0.050 \)), and a 2.7° decrease in knee abduction excursion (effect size = 1.17, \( P = 0.008 \)). However, no changes were identified in peak contralateral pelvic drop angle or excursion, peak hip adduction angle or excursion, or peak knee adduction angle. (Table 2)

### DISCUSSION

The purpose of the current study was to evaluate whether a movement training program using visual feedback and weekly instruction and manual facilitation of lower extremity alignment affects hip and knee joint frontal plane running mechanics among females with evidence of altered weight bearing kinematics. At the end of this 4-week training program, participants displayed decreased internal hip and knee abduction joint moments, decreased knee abduction excursion, and increased knee adduction excursion during stance while running. The intervention in this study translates well to clinical practice because it does not utilize special equipment and requires relatively few visits with the therapist. As such, these findings may be relevant to clinicians looking for methods to improve altered running mechanics observed in their patients.

Increased frontal plane hip and knee joint moments have been identified among individuals with overuse injuries and degenerative conditions such as patellofemoral pain and medial compartment knee osteoarthritis.\(^3\)\(^,\)\(^4\)\(^,\)\(^23\) It has been hypothesized that increased internal hip and knee abduction moment during running results in greater force on the lateral facet of the patella through greater contributions from the vastus lateralis, extensions of the iliotibial band, or both.\(^4\) Greater force on the patella from these tissues may result in greater retropatellar stress and activation of nociceptive fibers in patellar subchondral bone or synovium.\(^3\)\(^,\)\(^4\) Decreasing frontal plane hip or knee joint moments during running may therefore have clinical relevance by reducing retropatellar stress and symptoms experienced by individuals during routine exercise. However, to the authors knowledge only two previous studies report effects of exercise interventions to reduce hip and knee joint moments during running.\(^24\)\(^,\)\(^25\) Snyder et al reported that a 6-week hip strengthening program was associated with a 10% decrease in knee abductor moment during running.\(^24\) Earl et al reported 15% and 23% decreased internal hip and knee abductor moments during running, respectively following an 8-week "proximal stability program" that included five weeks of training including attention to lower extremity alignment during exercises for patellofemoral pain.\(^25\) Following the movement training provided in this study, internal hip and knee abduction moments decreased by 23% and 29%, respectively. The relatively large training effects found in both the present study and by Earl et al support the notion that attention to lower extremity alignment...
may be a more important component of interventions used to modify running mechanics than interventions that include strengthening alone.

In addition to smaller frontal plane internal hip and knee joint moments, participants also demonstrated less knee abduction excursion and increased knee adduction excursion during the stance phase of running after the movement training program. These effects suggest a less medial knee position during running that may be beneficial for the participants who demonstrated the most negative (medial) frontal plane projection angles displayed during a single leg squat. A medial knee position during the stance phase of running may affect the line of pull of the quadriceps and contribute to the etiology or exacerbation of overuse injuries such as patellofemoral pain. As such, this finding may be relevant for clinicians working with runners who experience this condition. Interestingly, to the authors’ knowledge, no previous studies of exercise-based programs used to modify running kinematics have reported significant changes in frontal plane knee angles or excursions. This novel finding may be related to the method used for participant selection. The subjects who were selected demonstrated the most medial knee position during a single leg squat activity. Therefore, it is possible that these participants had the greatest capacity for changing lower extremity kinematics and kinetics during the stance phase of running. Previous studies that have reported frontal plane knee joint kinematics following a hip strengthening or proximal stability training program did not screen potential subjects for evidence of altered weight bearing kinematics. As such, it may be reasonable to expect less change in such participants.

Despite kinematic and kinetic changes observed at the knee joint, the participants in the current study did not demonstrate changes in peak hip adduction or hip adduction excursion while running after the movement training program. This finding is consistent with three previous studies that also have reported no changes in frontal plane hip motion during running following a training program attempting to alter running mechanics. It has been suggested that to successfully alter running mechanics it may be necessary to include neuromuscular training during running within the exercise program. Both the interventions used in the current study and the intervention associated with three previous studies did not include feedback while actually running. To date, only one previous intervention to improve altered running mechanics included movement feedback during running. In that study, Noehren et al reported that 2-weeks of training using three-dimensional movement feedback during running resulted in decreased peak hip adduction during running among ten runners with patellofemoral pain. While this finding is notable because it suggests a plausible mechanism for changing hip joint running kinematics, future investigations may consider alternative methods to 3-D analysis that could provide performance based feedback during running that are feasible for widespread use in clinical settings. It is also worthwhile to highlight that although frontal plane hip joint kinematics were not affected by the training program utilized in the current study, frontal plane knee kinematics and kinetics were. Therefore, the results of the current study conflict somewhat with the premise that movement patterns emphasized during guided exercise programs do not transfer to running. Future studies are necessary to cross validate these findings and delineate the role of specificity of training on running mechanics.

The intervention in the current study was intended to limit the potential influence of muscle hypertrophic changes associated with exercise. Previous studies with the intent of changing running mechanics utilized interventions that lasted between 6 and 14 weeks. Based on the length of these studies, it is difficult to determine whether these changes observed in running mechanics were a result of hypertrophic strength gains or altered neuromuscular recruitment patterns. It has been suggested that increases in muscle force measured after fewer than five weeks of training are largely due to neuromuscular adaptations, whereas changes noted after five weeks are more closely associated with hypertrophic changes. Therefore, the gains seen in the current study conflict somewhat with the premise that movement patterns emphasized during guided exercise programs do not transfer to running. However, electromyographic analysis would be necessary to confirm or refute that the changes following this training program were associated with changes in lower extremity muscle activation level or timing during running.
The current study adds to a growing body of evidence for the effectiveness of using guided practice consisting of visual, verbal, and tactile feedback to modify movement patterns, but does not fully address questions regarding the time course and persistency of these changes. For example, changes in lower extremity running and landing mechanics have been reported after a single session of instruction or video feedback. The design of this study precludes the ability to discern the time course of changes in running mechanics among our participants during the 4-week training program. Based on the results of these previous studies it is possible that running mechanics changed very early in the training program and that 4 weeks of training is not necessary. Likewise, the persistency of the changes observed in this study is unknown. A future study with repeated assessment of running mechanics and a long-term follow up appears justified.

The presence of the investigator during motion analysis testing may have also influenced running mechanics. Subjects were not instructed to run differently during their follow-up motion analysis session. However, the authors did not include a placebo or control group that would mitigate this potentially confounding effect as well as clarify the influence of repeated testing, familiarity with the purpose of the study, and systematic differences in marker placement between visits. A future study with a control group that receives a placebo intervention program appears justified.

Delimitations of this study include the fact that all participants were healthy, highly motivated females who were compliant with the training program. As such, the generalizability of this study’s findings to males and a diverse clinical population remains uncertain. It is also worth noting that the authors chose not to report differences in running mechanics that may have occurred over time in the transverse plane. Relative to frontal plane kinematics, skin motion artifact adds significant variability to transverse plane kinematic data. As such, the authors chose not to include transverse plane variables, which also diminishes the possibility of type I error due to repeated statistical tests.

Despite uncertainty in the interpretation of the current results, the authors are encouraged by the fact that the participants in this study demonstrated systematic changes to hip and knee joint frontal plane running mechanics following a 4-week movement training program with a focus on visual, verbal, and tactile feedback of movement performance. This finding supports the possibility of changing running mechanics among individuals with altered movement patterns in a cost-effective manner.

**CONCLUSION**

Frontal plane hip and knee joint mechanics may contribute to running-related overuse injuries. As such, cost-effective interventions to improve these running mechanics are desirable. Participants in this study demonstrated decreased hip and knee abduction moments, increased knee adduction excursion, and decreased knee abduction excursion after a 4-week movement training program with a focus on verbal and visual feedback and manual neuromuscular facilitation techniques. Within the context of the limitations of this study, clinicians may consider these methods to improve running mechanics among females who demonstrate a medial knee position during a step down task.

**REFERENCES**


ABSTRACT

Background Context: Low back pain (LBP) is a prevalent disorder in society that has been associated with increased loss of work time and medical expenses. A common intervention for LBP is spinal manipulation, a technique that is not specific to one scope of practice or profession.

Purpose: The purpose of this systematic review was to examine the effectiveness of physical therapy spinal manipulations for the treatment of patients with low back pain.

Methods: A search of the current literature was conducted using PubMed, CINAHL, SPORTDiscus, ProQuest Nursing and Allied Health Source, Scopus, and Cochrane Controlled Trials Register. Studies were included if each involved: 1) individuals with LBP; 2) spinal manipulations performed by physical therapists compared to any control group that did not receive manipulations; 3) measurable clinical outcomes or efficiency of treatment measures, and 4) randomized control trials. The quality of included articles was determined by two independent authors using the criteria developed and used by the Physiotherapy Evidence Database (PEDro).

Results: Six randomized control trials met the inclusion criteria of this systematic review. The most commonly used outcomes in these studies were some variation of pain rating scales and disability indexes. Notable results included varying degrees of effect sizes favoring physical therapy spinal manipulations and minimal adverse events resulting from this intervention. Additionally, the manipulation group in one study reported statistically significantly less medication use, health care utilization, and lost work time.

Conclusion: Based on the findings of this systematic review there is evidence to support the use of spinal manipulation by physical therapists in clinical practice. Physical therapy spinal manipulation appears to be a safe intervention that improves clinical outcomes for patients with low back pain.

Keywords: Low back pain, manipulation, manual therapy, spine

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INTRODUCTION

Low back pain (LBP) is a common, disabling disorder that places a burden on individuals and society, resulting in associated loss of work productivity and increased medical costs.\(^1\,^3\) It has been proposed that LBP has a point prevalence of 6% to 33%\(^4\,^6\) and 1-year prevalence of 22% to 65%.\(^5\) Lifetime prevalence of LBP has been suggested to be approximately 84%.\(^7\) However, this estimate is likely to fluctuate from study to study based on the variable definitions of LBP, patient populations studied, and study design.\(^6\)

Spinal manipulation is a common, safe intervention that is applied to patients with various forms of low back pain. By definition, spinal manipulation is a localized or globally applied, single, quick, and forcible movement, alternately termed “high-velocity thrust”, of small amplitude, following careful positioning of the patient.\(^9\) The procedure is differentiated from mobilization in that a thrust is applied during the technique, versus lower velocity repetitive oscillations or sustained holds.\(^10\) Spinal manipulation has been advocated in clinical practice guidelines for low back pain,\(^11\) with evidence that exists to support the use of spinal manipulation for improvement of pain and function in patients with acute LBP.\(^1,^12\) In contrast, there are conflicting reports on the effectiveness of spinal manipulation for chronic LBP.\(^1,^12^-^15\)

Spinal manipulative therapy is used by a number of healthcare professions, including physical therapists, chiropractors, osteopathic physicians, and medical physicians. The use by physical therapists (PT) has been challenged regarding whether manipulation falls within their scope of clinical practice.\(^16\) A 2004 survey suggested that spinal manipulative therapy is a treatment technique that is taught to the majority of physical therapy students during didactic and clinical training.\(^17\) Although initially underutilized by physical therapists, momentum and adherence to evidence-based practice have enhanced the efforts to improve clinical reasoning for selection and delivery of such techniques.\(^18\) Concurrent with the increased use in the clinic have been published contributions by physical therapists on the effectiveness of spinal manipulation, and the recognition of these publications by other healthcare professions.\(^19\) Yet, to the authors’ knowledge, there has been no successful attempt to effectively and comprehensively define outcomes associated with physical therapy manipulation and describe the effectiveness of this intervention for patients with low back pain.

The objective of this systematic review was to analyze the effectiveness of physical therapy spinal manipulations for the treatment of patients with LBP. Effectiveness was determined by analyzing studies that compared physical therapy spinal manipulations with other interventions and included at least one clinically relevant outcome measure. Additionally, adverse effects, or unintended consequences of treatment,\(^20\) were taken into consideration when determining the effectiveness of this intervention. Findings from this systematic review may improve the understanding of whether spinal manipulative therapy, when performed by physical therapists, is a useful clinical procedure in practice.

METHODS

Study Design

The authors of this systematic review used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines during the search and reporting phase. The PRISMA Statement is composed of a 27-item checklist and a four-phase flow diagram which assists in reporting systematic reviews and meta-analyses.\(^21\) PRISMA can be used to report systematic reviews of various forms of research, most notably randomized controlled trials.\(^19\) These guidelines are helpful prospectively in the design and framework of a systematic review, but are not designed for use in retrospective assessment of quality.

Eligibility Criteria

Decisions for inclusion of published studies were based on the following Population, Intervention, Control, Outcomes, and Study design (PICOS) criteria\(^22\) defined for this systematic review as:

Population: Individuals with low back pain

Intervention: Spinal manipulations performed by physical therapists

Control: Any control group which did not receive physical therapy manipulation
Outcomes: Clinical outcomes (ie. quality of life, pain, disability) and efficiency of treatment (ie. costs, treatment time frame, number of visits, return to work)

Study Design: Randomized controlled trials (RCTs)

Only studies published in English were considered for review. Studies had to compare spinal manipulation to any other treatment approach and clearly distinguish spinal manipulation from other manual interventions. Manipulation had to be recognized as a high velocity-low amplitude (HVLA) thrust technique. Also, each article needed to clearly report that the spinal manipulations were performed exclusively by physical therapists. During instances in which this information was not clearly reported, the appropriate authors were contacted for clarification.

Information Sources

Individualized, computer-based search strategies for PubMed, CINAHL, Scopus, SPORTDiscus, ProQuest Nursing & Allied Health Source, and Cochrane Central Register of Controlled Trials databases (Appendix 1) were developed on May 14, 2012.

Search

PubMed was searched using a comprehensive search strategy that included search terms related to spinal manipulation for low back pain. There were no limits applied to the publication date of articles, but the following limits were applied to the search results: (1) Humans and (2) studies published in English. All remaining databases were searched using comparable strategies (Appendix 1).

Study Selection

The review process was performed by two independent authors (using a third author to resolve disagreements) for the 1) title search, 2) abstract search, and 3) full text search. Reasons for excluding full-text articles were documented. Kappa values were calculated as a measure of interrater reliability for agreement between title, abstract, and full-text reviewers. Commonly, kappa scores are interpreted as poor (<0.20), fair (0.21-0.40), moderate (0.41-0.60), strong (0.61-0.80), or near complete agreement (>0.80).

Data collection process

Data was extracted from each article by one author and a second author verified the information regarding methods, outcome measures, and adverse effects. The extracted information related to methods was as follows: (1) study type; (2) study setting and population; (3) description of physical therapy manipulation for experimental group; (4) description of intervention for control group; and (5) outcome measures. The extracted information related to outcome measures was as follows: (1) group means at baseline and each follow-up point or mean differences and 95% confidence intervals and (2) statistical significance of group differences. The extracted information related to adverse effects was as follows: (1) type of adverse event; (2) number of adverse events resulting from physical therapy manipulation; and (3) number of adverse events resulting from other interventions.

Risk of Bias

Each full-text article was reviewed independently by two authors and scored with the PEDro quality assessment tool. Disagreements in scoring were determined by consensus. This retrospective tool was designed to evaluate the internal validity and statistical reporting of randomized control trials. A higher rating on the PEDro scale is indicative of a study of better quality.

Synthesis of results

The results from reported outcome measures were synthesized to determine whether the manipulation group was considered superior, equal, or inferior to the control group based on the statistical significance reported in the studies. If studies reported mean differences and standard deviations a Cohen's effect size was calculated. Cohen's $d$ effect sizes are magnitude measures that describe the extent of the improvement of one group over another. Effect sizes typically are interpreted as minimal (0.20), moderate (0.50), or large (0.80).

RESULTS

Study selection

The database searches resulted in a total of 2,943 total citations that were reviewed for inclusion. After screening, 52 full-text articles were reviewed and six were deemed eligible. In all six studies spinal manipulation was provided to the low back. Reasons for excluding full-text articles included non-randomized controlled trials (n = 10), spinal manipulations not provided by physical therapists (n = 19),
manipulations not defined as high-velocity low-amplitude thrust technique (n=4), treatment group received high-velocity low-amplitude thrust manipulation with additional manual therapy (n=12), one published thesis was inaccessible through our institution’s library (n=1), and use of duplicate data (n=1). Figure 1 provides an explanation of the methods to obtain the final list of full-text articles. The calculated kappa scores for the inter-rater reliability of title reviews, abstract reviews, and full-text reviews were 0.830 (95% CI = 0.802, 0.853), 0.862 (95% CI = 0.767, 0.897), and 0.912 (95% CI = 0.480, 0.912), respectively. In general there was a lack of homogeneity among inclusion criteria, outcomes measures, and length of data collection, thus, the authors elected not to perform a meta-analysis.

**Study characteristics**

Of the six studies included, four were retrieved from PubMed\textsuperscript{26-29} and two from CINAHL.\textsuperscript{30,31} These studies

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**Figure 1.** Study flow for the systematic review.
were published between 2004 and 2009. The full details of all included studies can be found in Table 1.

**Risk of bias within studies**

Risk of bias within the individual studies was assessed using the PEDro scale and results are as follows. One study scored 6/10,30 two scored 7/10,26,29 and 3 scored 8/10,27,28,31 No studies met criteria five (blinding of all subjects) and six (blinding of therapists administering therapy) due to the constraints of study design and inability to effectively blind the patients and physical therapists to the interventions. Table 2 provides full details of the PEDro scoring for all included studies.

**Self-Report Outcomes for Pain and Disability**

The results for two studies29,31 that provided patient self-report pain outcomes involving means and standard deviations of between groups measures are reported in Table 3. Both studies analyzed longitudinal effects on pain and disability findings and neither study identified superior effects of manipulation versus a comparator group. Ironically, both involved imbalanced baseline findings; one31 exhibiting significance differences in Oswestry Disability Questionnaire (ODQ) scores.

The remaining four studies26-28,30 that evaluated mean between group differences (and 95% confidence intervals) are reported in Table 4. Outcomes measures included the ODQ, and the pain measures of temporal summation (reported as 0 to 100) using either the Numeric Pain Rating Scale (NPRS), and the Visual Analog Scale (VAS) for pain. In all four studies,26-28,30 manipulative therapy (and in one case manipulation and exercise30) demonstrated significant improvements over the comparator groups. Comparative groups consisted of use of a stationary bicycle, lumbar extension exercises, non-thrust mobilization, exercise, and ultrasound.

**Additional Outcomes Measures**

Additional measures at baseline and follow up were also captured by two of the six studies27,28 and is reported in Table 5. Childs and colleagues27 reported differences in medication use, pursuance of treatment for LBP, and work lost between those who received manipulation and those who did not and found significant improvements in all categories associated with those who received manipulation. Hallegraeff et al29 measured differences in spinal mobility but found no differences between groups. Many other studies performed multiple additional measures at baseline examination, but failed to report follow up measures.

**Effect Size Calculations**

Only two studies reported means and standard deviations.29,31 Hallegraeff and colleagues29 reported effect sizes of 0.31 favoring manipulation for pain at 2.5 weeks and 0.0 favoring no intervention on disability percentage. Venegas-Rios et al31 reported effect sizes of 0.08 and 0.19 for pain at 1 week and 4 weeks respectively, each favoring the manipulation and exercise group and effect sizes of 0.48 and 0.45 for the ODQ favoring manipulation and exercise. The authors also reported effect sizes of 0.005 and 0.07 at 1 week and 4 weeks respectively with the Roland Morris Disability Questionnaire, suggesting no real benefit of one intervention over the other.

**Risk of bias across studies**

There were several common instances of potential bias across the included studies. First, most studies used subjective outcome measures to determine the effectiveness of selected interventions. This, by definition, creates the potential for self-report bias and inaccurate outcomes. Secondly, the design of the studies did not allow for adequate blinding of the therapists, which may lead to expectation bias. Finally, there were no true control groups in any of the six studies. This design does not account for the possibility of spontaneous recovery that may occur naturally in some cases of acute nonspecific LBP.

**Adverse Effects**

Only one study28 reported the presence of adverse effects. Cleland et al28 found that 25 percent of patients within the study reported these side effects. Nine patients in each spinal manipulation group reported side effects, whereas 10 patients in the non-thrust manipulation (comparative) group reported such effects. Although no serious complications were reported, the most common side effects included aggravation of symptoms and stiffness. All adverse effects were reported to be resolved within 48 hours of onset.
<table>
<thead>
<tr>
<th>Author (year)</th>
<th>Participants Details</th>
<th>Inclusion Criteria</th>
<th>Exclusion Criteria</th>
<th>SM Group (No. sessions Duration Participants)</th>
<th>CG1 (No. sessions Duration Participants)</th>
<th>CG2 (No. sessions Duration Participants)</th>
<th>Outcome Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bialosky et al</strong> (2009)</td>
<td>36 initial participants 0 Drop outs</td>
<td>Age: 18-60 y Current LBP</td>
<td>Non-English speaking Systemic medical conditions Psychiatric medications Pregnancy S&amp;S of nerve root compression History of surgery to low back</td>
<td>HVLA 1 session 5 minutes n = 12</td>
<td>Stationary bike, 60-70 rpm 1 session 5 minutes n = 12</td>
<td>Prone low back extension exercise, 3 sets of 15 repetitions 1 session 5 minutes n = 12</td>
<td>Aδ fiber-mediated pain sensitivity Temporal summation</td>
</tr>
<tr>
<td></td>
<td>Mean Age (S.D.): SM = 29.58 y (11.07) CG1 = 34.33 y (13.96) CG2 = 33.25 y (13.27)</td>
<td>Females (%): SM = 8 (67) CG1 = 6 (50) CG2 = 12 (100)</td>
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<tr>
<td><strong>Childs et al</strong> (2004)</td>
<td>131 initial participants 12 Drop outs</td>
<td>Age: 18-60 y LBP ODQ ≥ 30%</td>
<td>Presences of any red flags Signs of nerve root compression Pregnancy History of surgery to low back or buttocks</td>
<td>HVLA, ROM exercises 5 sessions 4 weeks n = 70</td>
<td>Low stress aerobic and lumbar spine strengthening program 5 sessions 4 weeks n = 61</td>
<td>-</td>
<td>ODQ Self-reported pain scores</td>
</tr>
<tr>
<td></td>
<td>Mean Age (S.D.): SM = 33.3 y (11.2) CG1 = 34.6 y (10.6)</td>
<td>Females (%): SM = 30 (42.9) CG1 = 25 (41)</td>
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<tr>
<td><strong>Cleland et al</strong> (2009)</td>
<td>112 initial participants 0 Drop outs</td>
<td>Age: 18-60 y ODQ &gt; 25% Positive for spinal manipulation CPR</td>
<td>Presences of any red flags Signs of nerve root compression Pregnancy History of surgery to low back</td>
<td>Supine HVLA, spinal ROM exercises, strengthening and stabilization exercises 5 sessions 4 weeks n = 37</td>
<td>Side-Lying HVLA, spinal ROM exercises, strengthening and stabilization exercise s 5 sessions 4 weeks n = 38</td>
<td>Posterior-anterior nonthrust mobilization, spinal ROM exercises, strengthening and stabilization exercises 5 sessions 4 weeks n = 37</td>
<td>ODQ Numeric Pain Rating Scores</td>
</tr>
<tr>
<td>Author (year)</td>
<td>Participants Details</td>
<td>Inclusion Criteria</td>
<td>Exclusion Criteria</td>
<td>SM Group Intervention No. sessions Duration Participants</td>
<td>CG1 Intervention No. sessions Duration Participants</td>
<td>CG2 Intervention No. sessions Duration Participants</td>
<td>Outcome Measures</td>
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<tr>
<td>Hallegraeff et al\textsuperscript{19} (2009)</td>
<td>64 initial participants 1 Drop out</td>
<td>Age: 20–55 y Acute Nonspecific LBP &lt; 16 days</td>
<td>Specific low back pain Neurological signs</td>
<td>HVLA, standard physical therapy 4 sessions 2.5 weeks n = 31</td>
<td>Standard physical therapy 4 sessions 2.5 weeks n = 33</td>
<td>-</td>
<td>VAS for pain ODQ Sit-and-Reach Test Subjective Patient Report of Improvement</td>
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<tr>
<td>Mean Age: SM = 38 y CG = 40 y</td>
<td>With or without previous complaints</td>
<td>Specific rheumatic diseases Signs of osteoporotic fractures</td>
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<tr>
<td>Females (%): SM = 14 (41) CG1 = 15 (33)</td>
<td>No symptoms distal of the knee</td>
<td>Inability to fill in research questionnaires</td>
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<tr>
<td>Mosheni-Bandpe\textsuperscript{19} (2006)</td>
<td>120 initial participants 8 Drop outs</td>
<td>Age: 18–55 y LBP between L1-L5 and sacroiliac joints LBP &gt; 3 months S&amp;S referred from lumbar spine Good self-reported health Literate Speak &amp; understand English</td>
<td>History of treatment Receiving disability benefits Malignancy Obvious disc herniation Osteoporosis Visceral causes Infection or systemic disease of MS system Neurologic or sciatic nerve root compression Radicular pain Sensory disturbances Loss of strength and reflexes Previous vertebral fractures Major structural abnormalities Spine tumor Pregnancy Pacemakers</td>
<td>HVLA, exercise program Between 2-7 sessions n = 56</td>
<td>Exercise program, continuous US, n = 56</td>
<td>-</td>
<td>VAS for pain ODQ Modified-modified Schober’s test Surface EMG Muscle endurance</td>
</tr>
<tr>
<td>Mean Age (S.D.): SM = 34.8 y (10.6) CG1 =37.2 y (10.2)</td>
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<tr>
<td>Females (%): SM = 34 (61) CG1 = 32 (57)</td>
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<tr>
<td>Author (year)</td>
<td>Participants Details</td>
<td>Inclusion Criteria</td>
<td>Exclusion Criteria</td>
<td>SM Group Intervention</td>
<td>CG1 Intervention</td>
<td>CG2 Intervention</td>
<td>Outcome Measures</td>
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<tr>
<td>Venegas-Rios et al. (2009)</td>
<td>66 initial participants 5 Drop outs</td>
<td>Age: 21-65 y New referrals of patients with complaints of chronic LBP</td>
<td>Patients on follow-up appointments LBP caused by systemic or organic diseases Psychiatric disorders Pregnancy Acute severe pain needing immediate treatment or surgery History of back surgery, fractures, or osteoporosis CNS involvement Nerve root involvement from lumbar disc extrusion Lumbar disc sequestration Severely decreased DTR Severely decreased myotomal sensation Severely decreased MMT compared to contralateral side</td>
<td>HVLA, conventional physical therapy</td>
<td>Conventional physical therapy</td>
<td>-</td>
<td>VAS for pain ODQ Roland-Morris Disability Questionnaire Fear Avoidance Beliefs Questionnaire</td>
</tr>
</tbody>
</table>

SM = spinal manipulation; CG = control group; S.D. = standard deviation; y = years old; LBP = low back pain; S&S = signs and symptoms; HVLA = High-Velocity Low-Amplitude thrust manipulation; ODQ = Oswestry Low Back Pain Disability Questionnaire; CPR = clinical prediction rule; Standard Physical Therapy = gradually increasing the level of physical activity and improving the relevant physical functions, such as muscle strength, exercise capacity, and mobility; VAS = Visual Analogue Scale; MS = musculoskeletal; US = ultrasound at 1 MHz, 1.5 & 2.5 W/cm², 5-10 minutes; EMG = electromyography; DTR = deep tendon reflexes; MMT = manual muscle test.
### Table 2. Methodological quality of included studies using the PEDro Scale.

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<tr>
<th>Author, year</th>
<th>1</th>
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<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>Total</th>
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<tr>
<td>Bialosky et al., 2009</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td></td>
<td>X</td>
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<td>7/10</td>
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<td>Childs et al., 2004</td>
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<td>X</td>
<td>8/10</td>
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<td>Cleland et al., 2009</td>
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<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>7/10</td>
</tr>
<tr>
<td>Mohseni-Bandpei et al., 2006</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>6/10</td>
</tr>
<tr>
<td>Venegas-Rios et al., 2009</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>8/10</td>
</tr>
</tbody>
</table>

Criteria: 1. Eligibility criteria specified. 2. Random subject allocation. 3. Allocation was concealed. 4. Groups were similar at baseline. 5. Blinding of all subjects. 6. Blinding of therapists administering therapy. 7. Blinding of assessors. 8. Measures obtained from more than 85% of initial subjects. 9. All subjects received treatment or control. If not, data was analyzed by “intention to treat.” 10. Results of between-group comparisons reported for at least one key outcome. 11. Provides both point measures and measures of variability for one key outcome. PEDro item 1. Eligibility criteria specified is not used to calculate the overall PEDro score. X = criteria was satisfied.

### Table 3. Self-Report of pain and functional outcome results, demonstrating mean scores and standard deviations at time frames.

<table>
<thead>
<tr>
<th>Author (year)</th>
<th>Outcome measure</th>
<th>Time point</th>
<th>Manipulation Group Mean score (SD)</th>
<th>Comparative Group Mean score (SD)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hallegraeff et al. (2009)</td>
<td>VAS (0-100)</td>
<td>Baseline</td>
<td>42.7 (18.4)</td>
<td>54.0 (17.5)</td>
<td>N/R</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.5 weeks</td>
<td>19.0 (16.9)</td>
<td>24.8 (20.1)</td>
<td>p = 0.26</td>
</tr>
<tr>
<td></td>
<td>Disability %</td>
<td>Baseline</td>
<td>24.0 (18%)</td>
<td>26.0 (12%)</td>
<td>p = N/R</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.5 weeks</td>
<td>14.0 (17%)</td>
<td>14.0 (12%)</td>
<td>p = 0.38</td>
</tr>
<tr>
<td>Venegas-Rios et al. (2009)</td>
<td>VAS (0-100)</td>
<td>Baseline</td>
<td>58.61 (20.7)</td>
<td>55.52 (15.6)</td>
<td>p = 0.49</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1-week</td>
<td>43.94 (23.1)</td>
<td>46.76 (24.1)</td>
<td>N/R</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4-week</td>
<td>41.12 (27.3)</td>
<td>46.45 (27.6)</td>
<td>N/R</td>
</tr>
<tr>
<td></td>
<td>Intensity of pain</td>
<td>Baseline</td>
<td>15.85 (6.1)</td>
<td>19.82 (7.2)</td>
<td>p = 0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1-week</td>
<td>13.06 (7.7)</td>
<td>17.15 (9.1)</td>
<td>N/R</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4-week</td>
<td>12.97 (8.3)</td>
<td>17.12 (9.7)</td>
<td>N/R</td>
</tr>
<tr>
<td></td>
<td>ODQ (0-50)</td>
<td>Baseline</td>
<td>9.67 (4.3)</td>
<td>10.39 (4.3)</td>
<td>p = 0.49</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1-week</td>
<td>8.70 (5.0)</td>
<td>8.67 (5.3)</td>
<td>N/R</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4-week</td>
<td>8.55 (5.2)</td>
<td>8.94 (5.9)</td>
<td>N/R</td>
</tr>
<tr>
<td></td>
<td>RMDQ (0-24)</td>
<td>Baseline</td>
<td>8.70 (5.0)</td>
<td>8.67 (5.3)</td>
<td>N/R</td>
</tr>
</tbody>
</table>

All findings are reported as means and standard deviations for between groups changes at dedicated time points. NPRS = Numeric Pain Rating Scale; N/R = Not Reported; ODQ = Oswestry Disability Questionnaire; VAS = Visual Analog Scale; Disability, % = percentage of ODQ scores; NS = non-significant; RMDQ = Roland Morris Disability Questionnaire; SD = Standard Deviation.
Table 4. Mean between group differences (95% confidence intervals) in self-reported pain and functional outcome measures at time frames.

<table>
<thead>
<tr>
<th>Author (year)</th>
<th>Outcome measure</th>
<th>Assessment Time Point</th>
<th>Mean Between Group Differences (95% CI / SD)</th>
<th>Favorable Intervention</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bialosky et al. (2009)</td>
<td>Temporal Summation of Pain (0-100) SMT vs. Stationary Bike</td>
<td>Post-Intervention</td>
<td>12.3 (0.4 to 24.1)</td>
<td>SMT</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>Temporal Summation of Pain (0-100) SMT vs. Lumbar Extension Exercises</td>
<td>Post-Intervention</td>
<td>6.0 (-5.8 to 17.8)</td>
<td>N/A</td>
<td>NS</td>
</tr>
<tr>
<td>Childs et al. (2004)</td>
<td>ODQ (0-50) SMT versus Exercise</td>
<td>Baseline</td>
<td>0.5 (N/R)</td>
<td>N/A</td>
<td>&gt;0.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 week</td>
<td>9.2 (4.4 to 14.1)</td>
<td>SMT</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 weeks</td>
<td>8.3 (2.4 to 14.2)</td>
<td>SMT</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 months</td>
<td>10.1 (4.3 to 15.9)</td>
<td>SMT</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Cleland et al. (2009)</td>
<td>NPRS (0-10) Sidelying SMT vs. Nonthrust</td>
<td>Baseline</td>
<td>0.1</td>
<td>N/A</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1-week</td>
<td>1.5 (0.8 to 2.1)</td>
<td>SMT</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4-week</td>
<td>1.3 (0.5 to 2.2)</td>
<td>SMT</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6-month</td>
<td>0.4 (-0.3 to 1.1)</td>
<td>N/A</td>
<td>p=0.29</td>
</tr>
<tr>
<td></td>
<td>NPRS (0-10) Supine SMT vs. Nonthrust</td>
<td>Baseline</td>
<td>0.3</td>
<td>N/A</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1-week</td>
<td>2.1 (1.2 to 2.9)</td>
<td>SMT</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4-week</td>
<td>1.8 (0.7 to 2.9)</td>
<td>SMT</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6-month</td>
<td>0.6 (-0.3 to 1.4)</td>
<td>N/A</td>
<td>p=0.18</td>
</tr>
<tr>
<td></td>
<td>ODQ (0-50) Sidelying SMT vs. Nonthrust</td>
<td>Baseline</td>
<td>2.4</td>
<td>N/A</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1-week</td>
<td>7.9 (2.7 to 13.2)</td>
<td>SMT</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4-week</td>
<td>12.7 (7.5 to 17.9)</td>
<td>SMT</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6-month</td>
<td>6.8 (2.3 to 11.4)</td>
<td>SMT</td>
<td>p&lt;0.03</td>
</tr>
<tr>
<td></td>
<td>ODQ (0-50) Supine SMT vs. Nonthrust</td>
<td>Baseline</td>
<td>1.0</td>
<td>N/A</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1-week</td>
<td>11.5 (5.3 to 17.6)</td>
<td>SMT</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4-week</td>
<td>14.2 (8.0 to 20.4)</td>
<td>SMT</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6-month</td>
<td>5.9 (0.7 to 11.3)</td>
<td>SMT</td>
<td>p=0.03</td>
</tr>
<tr>
<td>Mohseni-Bandpei et al. (2006)</td>
<td>VAS (0-100) Manipulation + Exercise vs. Ultrasound + Exercise</td>
<td>Baseline</td>
<td>2.0</td>
<td>N/A</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6-months</td>
<td>16.4 (6.1 to 26.8)</td>
<td>SMT + Exercise</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30.8</td>
<td>17.9 (p=0.000)</td>
<td>Exercise</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>16.7 (p=0.003)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ODQ, (0-100%)</td>
<td>Baseline</td>
<td>1.4%</td>
<td>N/A</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 months</td>
<td>7.8% (2.4% to 13.2%)</td>
<td>SMT</td>
<td>p=0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6-month</td>
<td>13.2%</td>
<td>+Exercise</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NS</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NS</td>
<td>p=0.01</td>
</tr>
</tbody>
</table>

All findings are reported as means differences and 95% confidence intervals for between groups changes at dedicated time points. NPRS = Numeric Pain Rating Scale; N/R = Not Reported; ODQ = Oswestry Disability Questionnaire; VAS = Visual Analog Scale; Disability, % = percentage of ODQ scores; NS = non-significant;
DISCUSSION

Summary of evidence

Six randomized controlled trials were reviewed in order to determine the effectiveness of physical therapy spinal manipulations for patients with LBP. We calculated effect sizes for those studies that reported means and standard deviations. Effect sizes ranged from minimal to moderate for the outcomes measures. Worth noting is that the most robust effect size was associated with the use of the ODQ, a finding that yielded no effect when the same patients were evaluated with the Roland Morris Disability Questionnaire. In addition to the variations found with the instruments used to capture outcomes, variability in the findings is likely associated with study design differences, differences in the severity level of the patients, and potentially differences in the comparative intervention provided within each study.

All studies that reported mean differences and 95% confidence intervals found positive effects favoring manipulation (or manipulation and exercise) versus a comparator group. Improvements were significant in all cases for up to six months for disability scores and up to four weeks generally for pain oriented scores. Bialosky and colleagues reported improvements in temporal summation of pain (addition of stimuli over time) for those who received manipulation over lower back extension and stationary cycling as well.

The findings of this systematic review suggest that physical therapists have contributed to the growing wealth of literature that describes the effectiveness of spinal manipulation for the treatment of LBP. Although there was some inconsistency regarding the degree of effectiveness, all included studies in this systematic review reported data that supported the clinical usefulness of spinal manipulation provided by physical therapists. Previous systematic reviews have proposed that spinal manipulation can improve clinical outcomes, but its efficacy compared to other common intervention has not been clearly demonstrated. The results of this systematic review indicate that physical therapy spinal manipulation of the lumbar spine is an effective form of intervention for a variety of patients with low back pain, although the degree of effectiveness is variable between studies.

Only one study reported adverse effects of manipulation. Cleland et al showed that the non-thrust manipulation group (the sham comparative measure) actually reported more adverse effects than the two experimental thrust manipulation groups. The non-thrust manipulation group consisted of posterior to anterior mobilizations to the spinous processes of L4 and L5, and did not take into account

<table>
<thead>
<tr>
<th>Author, year (reference)</th>
<th>Additional outcomes</th>
<th>Time point</th>
<th>SMT Mean score (SD) / Mean Differences (95% CI)</th>
<th>CG1 Mean score (SD) / Mean Differences (95% CI)</th>
<th>Favorable Intervention</th>
<th>p-Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Childs et al., (2004)</td>
<td>Medication for LBP (%)</td>
<td>6-month</td>
<td>36.5% / 60.0%</td>
<td></td>
<td>SMT</td>
<td>P&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>Treatment for LBP (%)</td>
<td>6-month</td>
<td>11.5% / 42.5%</td>
<td></td>
<td>SMT</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>Work lost in past 6 weeks (%)</td>
<td>6-month</td>
<td>9.6% / 25.0%</td>
<td></td>
<td>SMT</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>Hallegraeff et al., (2009)</td>
<td>Spinal Mobility (mm)</td>
<td>Baseline</td>
<td>31.0 (7.6) / 29.7 (7.7)</td>
<td></td>
<td>NA</td>
<td>N/R</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.5 weeks</td>
<td>35.1 (8.5) / 35.2 (7.8)</td>
<td></td>
<td>NA</td>
<td>P=0.14</td>
</tr>
</tbody>
</table>

LBP = Low Back Pain; NA = Not applicable; N/R = Not reported; SMT = Spinal Manipulative Therapy; mm = Millimeters
patient feedback during the procedure. The techniques can be potentially irritating, which was similar to the minor adverse reactions reported by Cleland and associates. Cleland and others' findings of only minor adverse reactions are consistent with a systematic review by Bronfort et al which reported that serious or severe complications from spinal manipulations are rare. Certainly, future studies should more diligently report adverse events encountered during the study timeframe.

To the authors' knowledge, this is the first systematic review to examine the effectiveness of physical therapy spinal manipulation for LBP. One notable finding is that the majority of the studies examined only changes in pain and disability. Also, it should be noted that within the literature it has been reported that pain rating scales and ODQ measures are strongly correlated and may measure similar aspects of subjective pain reporting. Deyo et al suggests using a variety of outcome variables to truly reflect the complexity and multiple dimensions of LBP. Some notable outcomes proposed to be included in future studies are general well-being, work disability, satisfaction with care, and cost effectiveness. The one study examined in this systematic review that reported such outcomes supported the use of physical therapy spinal manipulation.

Limitations
This systematic review had a number of limitations. The search strategy was limited to include only studies published in English. Furthermore, none of the studies meeting the inclusion criteria obtained outcome measure data beyond six months following the treatment period. This limits the reporting of the long-term effects of physical therapy spinal manipulation for patients with LBP.

CONCLUSIONS
Physical therapy spinal manipulation appears to be a safe intervention that improves clinical outcomes for a variety of patients with LBP. Based on current literature, physical therapists should continue to use this intervention as one of many options to treat LBP. The authors of this systematic review suggest that further research be completed on this topic in an attempt to provide longer follow-up time periods and outcome measures which cover all significant components of patient outcomes.

REFERENCES


31. Venegas-Rios H. Effectiveness of low back pain manipulative therapy in combination with physical therapy as compared to standard physical therapy [e-book]. University of North Texas Health Science Center at Fort Worth; 2009.


APPENDIX 1. COMPREHENSIVE SEARCH STRATEGY FOR ALL DATABASES

**Database: PubMed**

#1 MeSH descriptor Low Back Pain, explode all trees
#2 MeSH descriptor Back Pain, explode all trees
#3 MeSH descriptor Lumbosacral Region, explode all trees
#4 MeSH descriptor Back, explode all trees
#5 MeSH descriptor Back Injuries, explode all trees
#6 "low back"
#7 "low back pain"
#8 lumbar
#9 lumbago
#10 “back pain”
#11 backache
#12 lumbosacral
#13 lbp
#14 [OR #1 - #13]
#15 MeSH descriptor Manipulation, Spinal, explode all trees
#16 MeSH descriptor Manipulation, Orthopedic, explode all trees
#17 MeSH descriptor Manipulation, Osteopathic, explode all trees
#18 manip*
#19 mobiliz*
#20 mobilis*
#21 “thrust”
#22 “grade 5”
#23 “high velocity”
#24 osteopath*
#25 [OR 15# - #24]
#26 MeSH descriptor Recovery of Function, explode all trees
#27 MeSH descriptor Health Care Costs, explode all trees
#28 MeSH descriptor Cost-Benefit Analysis, explode all trees
#29 MeSH descriptor Pain Measurement, explode all trees
#30 MeSH descriptor Comparative Effectiveness Research, explode all trees
#31 MeSH descriptor Treatment Outcome, explode all trees
#32 MeSH descriptor Program Evaluation, explode all trees
#33 MeSH descriptor Quality of Life, explode all trees
#34 MeSH descriptor Outcome Assessment (Health Care), explode all trees
#35 MeSH descriptor Office Visits, explode all trees
#36 recovery of function
#37 compara*
#38 compare*
#39 “cost-benefit”
#40 pain measur*
#41 effect*
#42 outcome*
#43 quality of life
#44 cost
#45 benefi*
#46 [OR #26 - #45]
#47 Clinical Trial [Publication Type]
#48 Randomized Controlled Trial [Publication Type]
#49 Comparative Study [Publication Type]
#50 Controlled Clinical Trial [Publication Type]
#51 Evaluation Studies [Publication Type]
#52 MeSH descriptor Random Allocation, explode all trees
#53 MeSH descriptor Follow-Up Studies, explode all trees
#54 random*
#55 clinical trial
#56 controlled trial
#57 [OR #47 - #56]
#58 [#14 AND #25 AND #46 AND #57]

Limits: Studies involving humans and publications in the English Language

**Database: CINAHL**

#1 MeSH descriptor Low Back Pain
#2 MeSH descriptor Back Pain, explode all trees
#3 MeSH descriptor Back Injuries, explode all trees
#4 MeSH descriptor Lumbar Vertebrae
#5 “low back pain”
#6 “low back”
#7 lumbago
#8 lbp
#9 lumbosacral
lumbar
“back pain”
backache
[OR #1 - #12]
MeSH descriptor Manipulation, Orthopedic
MeSH descriptor Manipulation, Osteopathic
manip*
mobiliz*
mobilis*
“thrust”
“high velocity”
osteopath*
[OR #14 - #21]
MeSH descriptor Recovery
MeSH descriptor Functional Assessment, explode all trees
MeSH descriptor Functional Status
MeSH descriptor Costs and Cost Analysis, explode all trees
MeSH descriptor Health Care Costs, explode all trees
MeSH descriptor Cost Benefit Analysis
MeSH descriptor Pain Measurement
MeSH descriptor Clinical Effectiveness
MeSH descriptor Treatment Outcomes, explode all trees
MeSH descriptor Outcome Assessment
MeSH descriptor Outcomes Research
MeSH descriptor Quality of Care Research
MeSH descriptor Quality of Health Care, explode all trees
MeSH descriptor Quality Assessment, explode all trees
MeSH descriptor Quality Improvement, explode all trees
MeSH descriptor Quality of Life, explode all trees
MeSH descriptor Office Visits
recovery of function
compar*
“cost-benefit”
pain measure*
effect*
outcome*
quality of life
cost
benefi*
[OR #23 - #48]
MeSH descriptor Evaluation Research, explode all trees
MeSH descriptor Formative Evaluation Research
MeSH descriptor Summative Evaluation Research
MeSH descriptor Program Evaluation
MeSH descriptor Comparative Studies
MeSH descriptor Clinical Trials, explode all trees
MeSH descriptor Randomized Controlled Trials
MeSH descriptor Random Sample, explode all trees
random*
clinical trial
controlled trial
[OR #50 - #60]
[#13 AND #22 AND #49 AND #61]
Limits: Publications in the English Language

Database: Scopus, ProQuest Nursing & Allied Health Source
“low back pain”
lumbago
lumbosacral
lbp
[#1 OR #2 OR #3 OR #4]
manip*
mobiliz*
mobilis*
[#6 OR #7 OR #8]
compar*
effect*
benefi*
[#10 OR #11 OR #12]
“clinical trial”
“randomized controlled trial”
“controlled trial”
[#14 OR #15 OR #16]
[#5 AND #9 AND #13 AND #17]
Limits: Peer reviewed articles from scholarly journals published in the English Language

Database: SPORTDiscus
DE "BACKACHE"
DE “BACK"
Database: Cochrane Central Register of Controlled Trials

#1 low back pain
#2 lumbar
#3 lumbago
#4 backache
#5 lumbosacral
#6 lbp
#7 [OR #1 - #6]
#8 manip*
#9 mobiliz*
#10 mobilis*
#11 osteopath*
#12 “thrust”
#13 “high velocity”
#14 [OR #8 - #14]
#15 “grade 5”
#16 recovery of function
#17 compar*
#18 cost benefit
#19 pain measur*
#20 effect*
#21 outcome*
#22 quality of life
#23 cost
#24 benefi*
#25 office visits
#26 [OR #16 - #25]
#27 clinical trial
#28 randomized controlled trial
#29 “controlled trial”
#30 random*
#31 [OR #27 - #30]
#32 [#7 AND #15 AND #26 AND #31]

Limits: Publications in the English Language

#3 DE “LUMBOSACRAL region”
#4 DE “LUMBAR vertebrae”
#5 DE “SACROCOXALGIA”
#6 low back pain
#7 lumbar
#8 lumbago
#9 backache
#10 lumbosacral
#11 lbp
#12 [OR #1 - #11]
#13 DE “MANIPULATION (Therapeutics)”
#14 DE “SPINAL adjustment”
#15 manip*
#16 mobiliz*
#17 mobilis*
#18 osteopath*
#19 “thrust”
#20 “grade 5”
#21 “high velocity”
#22 [OR #13 - #21]
#23 DE “PAIN -- Measurement”
#24 DE “QUALITY of life”
#25 DE “HEALTH status indicators”
#26 recovery of function
#27 compar*
#28 cost benefit
#29 pain measur*
#30 effect*
#31 outcome*
#32 quality of life
#33 cost
#34 benefi*
#35 [OR #23 - #34]
#36 clinical trial
#37 randomized controlled trial
#38 “controlled trial”
#39 random*
#40 [OR #36 - #39]
#41 [#12 AND #22 AND #35 AND #40]

Limits: Publications in the English Language
ABSTRACT

Background: Complete rupture of the distal tendon of the biceps brachii is relatively rare and there is little information to guide therapists in rehabilitation after this injury. The purposes of this case report are to review the rehabilitation concepts used for treating such an injury, and discuss how to modify exercises during rehabilitation based on patient progression while adhering to physician recommended guidelines and standard treatment protocols.

Case Presentation: The patient was an active 38-year old male experienced in weight-training. He presented with a surgically repaired right distal biceps tendon following an accident on a trampoline adapted with a bungee suspension harness. The intervention focused on restoring range of motion and strengthening of the supporting muscles of the upper extremity without placing undue stress on the biceps brachii.

Outcomes: The patient was able to progress from a moderate restriction in ROM to full AROM two weeks ahead of the physician's post-operative orders and initiate a re-strengthening protocol by the eighth week of rehabilitation. At the eighth post-operative week the patient reported no deficits in functional abilities throughout his normal daily activities with his affected upper extremity.

Discussion: The results of this case report strengthen current knowledge regarding physical therapy treatment for a distal biceps tendon repair while at the same time providing new insights for future protocol considerations in active individuals. Most current protocols do not advocate aggressive stretching, AROM, or strengthening of a surgically repaired biceps tendon early in the rehabilitation process due to the fear of a re-rupture. In the opinion of the authors, if full AROM can be achieved before the 6th week of rehabilitation, initiating a slow transition into light strengthening of the biceps brachii may be possible.

Keywords: Distal biceps tendon surgical repair, rehabilitation guidelines

Level of evidence: 4-Single Case report
BACKGROUND AND PURPOSE

Complete rupture of the distal tendon of the biceps brachii is relatively rare and there is little information to guide therapists in rehabilitation after this injury and subsequent surgical repair. A regimented physical rehabilitation program of resistance training and stretching is warranted for patients who sustain a distal biceps tendon rupture and undergo surgical reattachment of the tendon. In the opinion of the authors, such a protocol may be effective in promoting full recovery and return to functional and athletic activities.

Complete rupture of the distal biceps brachii accounts for approximately 3% of all biceps ruptures (the long head ruptures account for 96% and the short head 1%). The loss of function from a distal biceps tendon rupture is substantial secondary to the total loss of torque produced by the biceps brachii resulting in decreased strength in elbow flexion and supination, and recovery can be slow. Therapists and other exercise professionals need to be aware of the best practices following this injury. The most common mechanism of injury is a single unanticipated load placed on the elbow joint while in a flexed position. An audible “pop” is usually heard followed by an visually observable abnormal contour of the upper arm. In almost all cases, conservative treatment without surgical reattachment of the distal tendon to the radial tuberosity has been shown to leave patients with markedly decreased muscular strength and endurance of forearm supination and elbow flexion. Therefore, immediate surgical repair is the recommended course of action. However delayed surgical treatment (3 weeks to 5 months after diagnosis) has been shown to be equally beneficial in long term follow-up results when compared to patients treated early (within 8 days of initial injury).

The biceps brachii is the main flexor at the elbow joint and a powerful supinator when the elbow is in a flexed position. It also aids with shoulder flexion, stabilization of the humeral head during deltoid contraction, and can assist in abduction and internal rotation of the humerus. Proximally, the long head of the biceps originates at the supraglenoid tubercle of the scapula and the short head from the coracoid process of the scapula. Distally, the biceps inserts on the radial tuberosity and via the bicipital aponeurosis (Figure 1).

The two types of surgical procedures commonly used are the single-incision technique and the double-incision technique (Figures 2 and 3). Numerous studies have been performed examining the different methods of surgical repair of the distal biceps brachii tendon tear as well as long term results of operative vs. non-operative treatments in terms of strength and range of motion (ROM) recovery. Younger patients with higher activity levels demonstrate improved recovery of ROM as compared to similar injuries sustained by those in an elderly population, yet there is limited information available to guide therapists and other exercise professionals with regard to strengthening of the muscle post-surgery.
rehabilitation, strengthening exercises (which stress the suture anchor) have commonly been prohibited due to fear of re-rupturing the tendon. Although new surgical techniques are being developed that have demonstrated the ability for surgically repaired tendons to withstand higher loads prior to failure, recommendations for the introduction of strengthening exercises post-surgery have not been modified to reflect these surgical advances. For example, Heinzelmann et al recently found that repair of a distal biceps tendon rupture with use of a soft tissue button and interference screw technique through a limited anterior incision can allow for a greater repair strength, thus allowing for earlier aggressive rehabilitation such as a progression to light pain-free strengthening at only 2 weeks postoperative.

Rehabilitation of a surgically repaired distal biceps tendon typically follows two phases: first immobilization, either with a cast or hinged brace, in order to limit full motion for the first 6 postoperative weeks, and a second phase that focuses on strengthening the atrophied muscles and eventual return to functional activities. In a retrospective review of 113 patients who underwent therapy for distal biceps repairs, Cheung et al reported that by increasing ROM through the use of a hinged brace with an extension restriction originally set at 60° of flexion and decreasing 20° every two weeks, full extension was achieved by week six, with strengthening of the biceps starting during the eighth week. More conservative treatment protocols have documented placing the injured extremity in a cast for six weeks, with restrictions on active stretching even at the

![Figure 2. Single-incision technique for distal biceps tendon repair. Used with permission from The Journal of Shoulder and Elbow Surgery.](image)

![Figure 3. Double-incision technique for distal biceps tendon repair. Used with permission from The Elbow and Its Disorders. Copyright Elsevier (2000).](image)
12th post-operative week, and a strengthening phase initiated only at the 16th post-operative week. There is little information on more aggressive rehabilitation protocols for this type of surgery. The descriptions of the treatments described in this case report may help guide physical therapists in the rehabilitation of a patient with a ruptured distal biceps brachii tendon that has been surgically repaired.

The purposes of this case report are to: 1) present the rehabilitation protocol used with an individual with a surgically repaired ruptured distal biceps tendon, 2) review the rehabilitation concepts used for developing the protocol for treating such an injury, and 3) discuss how to modify exercises during the rehabilitation process based on patient progression while still adhering to the physician recommended guidelines.

Case Description: Patient History
The patient was an active, 38-year old male who participated regularly in resistance training. He underwent surgical repair of the right distal biceps tendon following an accident on a trampoline adapted with a bungee suspension harness. While in the ascending phase of his jump, the patient held on too tightly to the trampoline bungee cords attached to the harness causing his right upper extremity to forcibly abduct resulting in an extension torque at his elbow joint against the elbow being held in flexion. This mechanism of injury resulted in an eccentric overload on the distal biceps muscle tendon causing it to tear away from the insertion at the radial tuberosity. The patient described hearing a “popping” sound followed by sudden sharp and severe pain. Magnetic resonance imaging (MRI) of the upper extremity revealed complete rupture of the distal biceps brachii. Surgery was performed 15 days after the initial injury using a single-incision technique. Informed consent was given by the patient to be presented in this publication

Clinical Impression #1
Prior to the injury the patient was highly active, participating in resistance training exercise 4-5 times a week. Following the injury, his goal was to return to his previous exercise schedule. Based on his history, mechanism of injury, and the level of invasiveness with the surgical procedure to reattach the biceps tendon, the authors anticipated that he might demonstrate severe limitations in elbow joint ROM accompanied with high levels of pain. Based on subsequent observations, the initial plan for examination included assessment of ROM and pain levels with a verbal numeric rating scale (NRS) and no manual muscle testing (MMT) per physician orders.

Examination
The patient presented with the right upper extremity in a brace, locked at 90° of elbow flexion (Figure 4). Physician orders at the time called for no active flexion of the elbow or supination at the forearm. Review of the patient’s history indicated no previous musculoskeletal injuries to the upper extremities and no major cardiopulmonary, integumentary, neuromuscular, or other medical issues that might impede recovery or participation in rehabilitation. Physical examination of the injured region revealed a visible and palpable deformity of the biceps brachii muscle belly, primarily in the distal region, with a small scar in the right antecubital fossa where the biceps tendon had been surgically reattached. The scar was approximately three cm in length and was healing well without any signs of infection.

Active range of motion (AROM) was assessed bilaterally with a standard (universal) goniometer. AROM of the right (involved) elbow joint into flexion and extension revealed dramatic decreases when compared to the contralateral side, with pain of 3/10 reported using the NRS that occurred at the end of
his range of motion (Table 1). At the time of the initial evaluation, no MMT’s were performed due to physician prescribed precautions. Elbow joint mobility presented with major restrictions. A restricted end-feel was found with arthrokinematic assessment in the humeroulnar, humeroradial, superior radioulnar and inferior radioulnar motions.

<table>
<thead>
<tr>
<th>Motion</th>
<th>Right Upper Extremity</th>
<th>Left Upper Extremity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion</td>
<td>130 deg</td>
<td>150 deg</td>
</tr>
<tr>
<td>Extension</td>
<td>35 deg flexion</td>
<td>0 deg</td>
</tr>
<tr>
<td>Supination</td>
<td>85 deg</td>
<td>90 deg</td>
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<tr>
<td>Pronation</td>
<td>50 deg</td>
<td>90 deg</td>
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</tbody>
</table>

deg= degrees of active range of motion

Clinical Impression #2
Based on the physical examination, previous level of functioning and past literature evidence it was evident hypothesized that if full AROM could be regained the patient would have minimal difficulties in returning to his previous level of activity including heavy resistance training. Per physician orders, exercises that actively contracted the biceps muscle were prohibited until the eighth week of rehabilitation.

Intervention
Initially interventions were focused on restoring range of motion using PROM, stretching, and grades three and four joint mobilizations, along with devising exercises to strengthen supporting scapular stabilizing muscles of the upper extremity without placing undue stress on the biceps brachii. (Figure 5) Range of motion was assessed actively and passively every one to two weeks.

After the first two weeks of physical therapy the patient reported no increase in soreness. Appendix 1 presents the rehabilitation protocol used with this patient. He also was compliant with a home exercise program (HEP) of AROM exercises of the elbow, shoulder, and forearm similar to those performed in the clinic. Exercises were to be performed at home in all planes of movement for three sets of twenty repetitions to end range of motion, three times daily. Currently available rehabilitation protocols limit active contraction of the biceps brachii muscle until weeks 8-10 (Figure 5). In order to strengthen other muscles, such as the scapular and glenohumeral stabilizers (rhomboids, latissimus dorsi, middle trapezius, etc), an exercise was developed in which the patient bilaterally actively retracted his scapulae and extended his shoulders at the gleno-humeral joint against elastic resistance (Figure 6). This exercise strengthens the scapular stabilizers without

Figure 5. Suggested rehabilitation program protocol for distal biceps repair. Note the protocol includes specific phases of rehabilitation starting from the acute post-surgery phase, extending to the return-to-play period.
placing additional stress on the biceps brachii muscle. Low biceps activity during performance of this exercise was confirmed by manual palpation. Recent evidence has shown that biceps brachii electromyographic activity during scapular retraction has been measured to be less than 10% of maximal voluntary contraction.18 The patient was also placed seated on an exercise ball during the exercise in order to help increase abdominal and trunk muscle recruitment.

At the end of week two, ROM was reassessed and demonstrated improvement when compared to baseline (Table 2). In addition, the patient's recovery of ROM was considered ahead of schedule, as the last measurement taken (5 degrees of flexion, or lacking 5 degrees from full extension) surpassed what the physician protocol had suggested by the beginning of week three (20 degrees of flexion) and week four (10 degrees of flexion). At week four, range of motion was assessed a third time. At this time, the patient had regained full passive extension without pain. Although the patient was still minimally limited in passive flexion, he was making a more rapid recovery than is typically observed.3,12,13

At post-operative week 3 the patient began phase II of rehabilitation (weeks 3-6), consisting of exercises that focused on strengthening supporting musculature including scapular stabilizers, shoulder rotator cuff, and forearm. The intensity of exercises already in the treatment protocol (Appendix 1) was gradually increased to progress toward complete recovery. At no time during the rehabilitation process did the patient experience any adverse reactions or increase in pain with any of the ROM or strengthening exercises.

After full AROM was achieved by week four, the authors determined that the patient was ready to initiate joint strengthening of the biceps muscle, however, physician orders prohibited this until the 8th week of rehabilitation (Figure 5). It was during weeks 8-10 that exercises were added to strengthen the biceps brachii specifically using single joint exercises such as bicep curls or multi-joint exercises such as the latissimus dorsi pull-down. At the 8th week, the patient reported that he had full function with his extremity and had no deficits with any activities of daily living (ADL).

### Outcomes and Discussion

Patients who sustain a distal biceps tendon rupture and who undergo surgical intervention for reattachment fully recover and return to both functional and athletic activities without limitations.3,15,19,20,21,22 In this case, the patient was able to fully recover AROM within 4 weeks and eventually return to strengthen-

| Table 2. Patient active range of motion in extension. Note how the patient’s range of motion differed than that of the physician recommendations. |
|---|---|---|
| | Initial Examination | 2 Weeks | 4 Weeks |
| Patient presentation | 35 deg of flexion | 5 deg of flexion | 0 |
| Physician Recommendations | x | 30 deg of flexion | 10 deg of flexion |
ing exercises without limitations by the 8th week of rehabilitation (Appendix 1). The rate at which the patient’s ROM normalized was faster than generally expected, and led the authors to implement newly devised exercises that enabled the patient to advance strengthening of supporting musculature of the upper back and shoulder girdle while limiting any contraindicated exercise or activity that involved the biceps. It could be that the patient was able to progress towards full extension ROM at a faster rate than previous protocols because of his history of advanced levels of physical activity and a high degree of motivation both of which are well known predictors for successful rehabilitation.3,4 Degree of physical activity level prior to injury has been shown to have a positive effect on rehabilitation potential and the level of post-injury motion and strength potential should be considered when managing the treatment process.2 These, along with the patient's relatively young age may also have contributed to achieving rehabilitation outcomes ahead of schedule. Overall, this article is just a case report, and generalizations to other/all patients who have undergone distal biceps repairs cannot be made.

The authors believe that the results of this case report add to the current knowledge regarding physical therapy treatment for a distal biceps tendon repair while at the same time provide insights for future protocol considerations in active individuals. Most current protocols do not advocate aggressive stretching, AROM, or strengthening of a surgically repaired distal biceps tendon early in the rehabilitation process due to the fear of a re-rupture. At this time the most information on aggressive early rehabilitation of the distal biceps repair has been provided by Cheung et al. They detail a progressive PROM protocol starting immediately and reaching full ROM by the sixth week.4 The patient in this case study, however, started AROM during week 1 and isotonic joint strengthening of the biceps at the start of week 8. The strengthening protocol described in the present report was consistent with the timeline of Cheung et al, but was more advanced than the physician orders prescribed (which indicated only isometric strengthening through weeks 8-10 before the advancement to isotonic exercises).4 Conversely, both of these protocols are more aggressive than the highly conservative procedures detailed by Thompson in which the injured extremity was placed in a cast for six weeks, with no active stretching until the 12th week, and no strengthening until the 16th week post-surgery.3

One factor that would have strengthened this case report would have been to document the return of strength in the patient's biceps brachii during the strengthening phase of the rehabilitation protocol as compared to his uninjured extremity. It would also have been beneficial to be able to detail the exact amount of HEP ROM exercises the patient actually performed, which most likely aided in his early recovery.

One concept that has not been investigated in the literature is the effect of strengthening exercises of the biceps (isometric or isotonic) early in the rehabilitation process, as soon as the patient can achieve full active ROM. Presently all published protocols for this particular surgery prohibit any strengthening until well into the eighth week or after. It is likely that these same protocols were not developed with the expectation that patients could recover full ROM by the end of the sixth week. In the opinion of the authors' if full AROM can be achieved before the sixth week of rehabilitation, initiating a slow transition into light strengthening of the biceps brachii may be safe for the patient and worth investigating. Future studies should evaluate the initiation of strengthening exercises when full AROM has been achieved in more patients.

CONCLUSION

The distal biceps brachii tendon rupture is a relatively rare injury and there is currently limited evidence available on rehabilitation techniques and guidelines for proper progression. In this case report, the rate at which the patient's ROM progressed during rehabilitation was faster than generally expected, and led the authors to implement newly devised exercises that enabled the patient to advance strengthening of supporting musculature of the upper back and shoulder girdle while limiting any contraindicated exercise or activity that involved the biceps. While the overall treatment plan did not differ significantly from the requested physician protocol, it is the authors' opinion that full AROM may be achieved before the sixth week of rehabilitation, and therefore, initiating a slow transition into light strengthening of
the biceps brachii may be safe for patients and worth investigating with future research with larger numbers of subjects.

REFERENCES


### APPENDIX 1: INTERVENTION PROTOCOL USED WITH THE SUBJECT OF THE CASE REPORT

<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5-6</th>
<th>Week 8-10</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Elbow</strong></td>
<td>AROM Ext: 2x10 (0 lbs)</td>
<td>AROM Ext: 2x10 (0 lbs)</td>
<td>AROM Ext: 2x10 (0 lbs)</td>
<td>AROM Ext: 2x10 (0 lbs)</td>
<td>AROM Ext: 2x10 (0 lbs)</td>
<td>AROM Ext: 2x10 (0 lbs)</td>
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<tr>
<td></td>
<td>Joint mobilizations as needed</td>
<td>PROM stretching ext/flex: 5x30 sec</td>
<td>PROM stretching ext/flex: 5x30 sec</td>
<td>PROM stretching ext/flex: 5x30 sec</td>
<td>PROM stretching ext/flex: 5x30 sec</td>
<td>PROM stretching ext/flex: 5x30 sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Joint mobilizations as needed</td>
<td></td>
<td></td>
<td></td>
<td>BOSU – Push Up</td>
</tr>
<tr>
<td><strong>Forearm</strong></td>
<td>Ext/Flex: 3x10 each direction (0 lbs)</td>
<td>Ext/Flex: 3x10 each direction (1 lbs)</td>
<td>Ext/Flex: 3x10 each direction (2 lbs)</td>
<td>Ext/Flex: 3x10 each direction (4 lbs)</td>
<td>Ext/Flex: 3x10 each direction (5 lbs)</td>
<td>Ext/Flex: 3x10 each direction (5 lbs)</td>
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<td></td>
<td></td>
<td></td>
<td>Tricep Extension – 2x10 (10 lbs)</td>
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<td></td>
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<tr>
<td><strong>Shoulder</strong></td>
<td>AROM flexion: 3x10 (Cane)</td>
<td>AROM flexion: 3x10 (1 lbs)</td>
<td>AROM flexion: 3x10 (1 lbs-3 lbs)</td>
<td>AROM flexion: 3x10 (5 lbs)</td>
<td>AROM flexion: 3x10 (5 lbs)</td>
<td>AROM flexion: 3x10 (5 lbs)</td>
</tr>
<tr>
<td></td>
<td>Shoulder stretching in all directions (Flex, Abd, ER, IR): 5x30 seconds</td>
<td>Shoulder stretching in all directions (Flex, Abd, ER, IR): 5x30 seconds</td>
<td>Shoulder stretching in all directions (Flex, Abd, ER, IR): 5x30 seconds</td>
<td>Shoulder stretching in all directions (Flex, Abd, ER, IR): 5x30 seconds</td>
<td>T-Band Ext: x30 reps (Green Band)</td>
<td>T-Band Ext: x30 reps (Green Band)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Shrug: x30 reps (5 lbs)</td>
<td>Shrug: x30 reps (8 lbs)</td>
</tr>
<tr>
<td><strong>Scapular Stabilizers</strong></td>
<td>Scapular retraction double T-Band on ball: 3x10 (Blue T-Band resistance)</td>
<td>Scapular retraction double T-Band on ball: 3x10 (Black T-Band resistance)</td>
<td>Scapular retraction double T-Band on ball: 3x10 (Silver T-Band resistance)</td>
<td>Scapular retraction double T-Band on ball: 3x10 (Silver T-Band resistance)</td>
<td>Scapular retraction double T-Band on ball: 3x10 (Silver T-Band resistance)</td>
<td>Scapular retraction double T-Band on ball: 3x10 (Silver T-Band resistance)</td>
</tr>
<tr>
<td></td>
<td>Scapular retraction into exercise ball: 2x10</td>
<td>Scapular retraction into exercise ball: 2x10</td>
<td>Scapular retraction into exercise ball: 2x10</td>
<td>Scapular retraction into exercise ball: 2x10</td>
<td>Scapular retraction into exercise ball: 2x10</td>
<td>Scapular retraction into exercise ball: 2x10</td>
</tr>
<tr>
<td></td>
<td>Serratus punches in supine: x30 reps (2 lb weight)</td>
<td>Serratus punches in supine: x30 reps (4 lb weight)</td>
<td>Serratus punches in supine: x30 reps (5 lb weight)</td>
<td>Serratus punches in supine: x30 reps (5 lb weight)</td>
<td>Serratus punches in supine: x30 reps (5 lb weight)</td>
<td>Serratus punches in supine: x30 reps (5 lb weight)</td>
</tr>
</tbody>
</table>

AROM = Active range of motion, PROM = Passive range of motion, lbs = pounds, Ext = Extension, Flex = Flexion, Abd = Abduction, ER = External rotation, IR = Internal rotation, T-Band = Thera-Band *
ABSTRACT

The management of the skeletally immature athlete sustaining injury to the anterior cruciate ligament and other knee structures provides multiple challenges for both the treating clinicians and parents of the injured child. The diagnostic process and subsequent decision making present additional complexities because of the developmental anatomy and the potential for disturbance of normal growth patterns by some surgical interventions. In the following case report, the course to appropriate management of a young athlete is detailed, including the contributions of imaging results. The reconstructive options available to orthopedic surgeons and the patient's post-operative progression are also briefly discussed. Rehabilitation practitioners require an understanding of the unique issues present when providing care for pediatric and adolescent athletes with knee injuries in order to assist in optimal decision making in the phases during which they are involved.

Level of Evidence: 5 (Single Case Report)

Key Words: Anterior cruciate ligament, adolescent, open physis, pediatric, skeletal immaturity

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INTRODUCTION
Management of patients with injuries to the anterior cruciate ligament (ACL) of the knee has become one of the most studied topics in musculoskeletal medicine and rehabilitation. Estimates are that approximately two million people worldwide experience ACL injuries annually. Although precise data are not available, an estimated 125,000 to 200,000 ACL reconstructions annually occur in the United States alone. Children and adolescent athletes account for 0.5% to 3.0% of all ACL injuries and the rate at which these injuries are occurring in these populations is increasing. American football athletes are known to have the greatest relative risk for sustaining knee injuries, followed closely by girl's soccer. When ACL injuries are specifically considered, however, girl's sports of soccer, basketball, and volleyball all have a higher rate of injuries proportionally than football.

While differential diagnosis must consider other pathologies such as meniscal tears, osteochondral injuries, tibial spine fractures, other ligament injuries, or epiphyseal fractures, individuals with ACL injuries often have those same pathologies and others as accompanying injuries. Young individuals with ACL tears have been reported to have concurrent meniscal injuries in 69% of the cases. The younger patient with the acute ACL injury often sustains a lateral meniscus tear at the time of the original trauma, while the young person with the chronically ACL deficient knee will be at risk for developing a medial meniscus tear. If reconstruction of the ACL is delayed beyond 12 weeks, the risk for irreparable meniscal injury significantly increases. Thus, efficient early management of the skeletally immature person suspected of having an ACL injury is imperative. Recent work continues to delineate the importance of the meniscus as a “chondral protective” structure with much poorer long-term outcomes occurring in those patients who have sustained meniscal injury and meniscectomy, either in isolation or accompanying other structural injury.

INJURY AND CLINICAL PRESENTATION
During a youth football game, an eight year-old athlete carried the ball toward the goal line, but was tackled prior to scoring a touchdown. During the contact that concluded the play, the young athlete experienced an injury to his right knee. He was observed to have planted his right foot to change directions in an attempt to avoid being tackled. While the right foot was planted and the left foot was moving toward a different direction, he was tackled by multiple opposing players, resulting in his trunk rotating to the left left on his fixed right lower extremity. He remained down on the field for a moment, reporting to his father “My knee popped. I think it’s broke [sic].” He was held from further competition during the game and treated with the application of ice to his knee. Effusion of the injured joint, as reported by his parents, was evident within 30 minutes. Within two days, the effusion and pain had largely resolved and his gait was approaching normal, without the use of an assistive devices. With squatting, running, and higher demand activities, however, his parents noticed a tendency for him to use compensatory mechanics for his right lower extremity. Although he returned to school with improving mobility, the parents sought medical decisions for providing the best care. Concern for disruption of normal growth, particularly limb length on the side of the affected knee, is the basis for this attention. The skeletally immature patient was once routinely treated with conservative measures in order to minimize the risk of disturbing normal growth, but this approach was found to have negative consequences as described in Janssen et al. Activity limitation, bracing, and exercise have proven largely unsuccessful in persons of this age group with ACL deficient knees with preventing meniscal injury and early onset of the degenerative cascade. Thus, surgical intervention is now generally considered to be the standard of care. Less clearly practiced, however, is how to best complete the diagnosis, reconstruction, and post-operative rehabilitation of the skeletally immature athlete with an ACL injury. These topics are explored in this case report of a pediatric patient who sustained an ACL injury, with subsequent reconstruction, and rehabilitation.
consultation first with a pediatrician, who then referred the patient to an orthopedic surgeon for evaluation. Radiography and a clinical examination were completed, but the initial orthopedic consultation did not yield diagnosis of a significant injury. The recommendation by the orthopedist was to allow the athlete to return to his prior activity level as indicated by his comfort level. The parents, dissatisfied with the outcome of the orthopedic assessment, sought an additional opinion. Further evaluation was completed by a family medicine physician with certification in sports medicine. This physician's clinical examination immediately raised suspicion of an ACL injury by the presence of a positive Lachman's test. Radiographs and magnetic resonance imaging (MRI) were promptly completed with a tear of the ACL being visualized along with suspicion of a lateral meniscus injury. The radiographs revealed no bony abnormality and the open physes of the femur, tibia, and fibula (Figures 1 and 2) were readily identifiable. The MRI revealed complete disruption of the ligament at the lateral wall of the femoral notch (Figure 3) and a lateral meniscus tear (Figure 4).

With surgical consultation being recommended by this physician, the parents were able to obtain an immediate assessment by another orthopedic surgeon. The next consultation sought by the parents for their son with an orthopedic surgeon resulted in the recommendation for ACL reconstruction using an allograft and a post-operative period of immobilization. An additional opinion was later offered by a pediatric orthopedic surgeon, who ordered bone age studies to supplement the MRI in the decision-making process. This physician recommended an all epiphyseal reconstruction to minimize risk to the growth plates using a hamstring autograft. He also discussed with the parents alternative reconstruction techniques, including an iliotibial extra-articular reconstruction and an adult-type reconstruction crossing the growth plates. Still yet another opinion was sought by the parents because of the apparently conflicting information provided in the prior consultations. The fourth orthopedist, known for helping develop the all epiphyseal reconstruction, offered a similar recommendation for an all epiphyseal technique using a hamstring autograft. After extensive deliberation, the parents chose for their son the all epiphyseal autograft technique under the care of the orthopedic surgeon offering the final consultation.

CLINICAL EXAMINATION
Clinicians should have an elevated index of suspicion for a ligamentous injury in the young athlete who presents with a traumatic hemarthrosis or reporting this to have occurred immediately after

Figure 1. This anterior-posterior radiograph indicates no bony abnormalities and the open physes of the tibia and fibula. The superimposed patella obscures view of the distal femoral physis.
the injury. Although joint effusion is a nonspecific sign, most ACL and meniscus injuries are accompanied by knee effusion. Effusion may also be present with Salter-Harris fractures and, thus, indicate the need for further investigation.

Among clinical examination procedures, the Lachman’s test, the pivot shift, and the anterior drawer test are most frequently used to evaluate for ACL injury. In a recently published meta-analysis, the Lachman’s test was determined to have the best combined psychometric values for identifying acute, complete ACL ruptures. The sensitivity and specificity were each calculated to be 81%. An earlier meta-analysis found the sensitivity and specificity values to be greater at 85% and 94%, respectively. In the more recent study, the values increased if the patient was examined under anesthesia, which points to the potential complication of apprehension by the patient interfering with examination procedure and interpretation of the results. Particular analysis of the diagnostic value of Lachman’s test and other clinical examination procedures in pediatric and adolescent athletes has not been thoroughly studied. Only one investigation has closely considered the accuracy of clinical examination and diag-

Figure 2. The lateral view radiograph demonstrates the open physes of the distal femur, and proximal tibia and fibula. No bony abnormalities are observed.

Figure 3. A proton density weighted MR sagittal slice image showing the lax ACL with its free-floating proximal end.

Figure 4. A proton density weighted MR sagittal slice image revealing a tear of the lateral meniscus. Note the well-defined zone of increased signal intensity in the posterior horn of the lateral meniscus.
nostic imaging for ACL tears specifically in this younger group of individuals with the results indicating comparable diagnostic accuracy as adults. Many studies routinely include younger persons in their study populations, but do not stratify the data based on age.

Other clinical examination procedures, particularly the pivot shift and anterior drawer tests, have been found to have less diagnostic accuracy than Lachman's test. The pivot shift maneuver has very high specificity, but low sensitivity, limiting its clinical utility. The anterior drawer test also has significantly less sensitivity than Lachman's test, particularly in the assessment of acute injuries, but may have greater diagnostic value in the presence of chronic ACL deficiency.

The commonly used clinical examination procedures for identifying meniscus tears have questionable clinical utility and also have had limited evaluation specifically in pediatric or adolescent patients. The clinical tests, particularly if flexion of the knee is not permitted by the patient, may not allow for a valid examination. Reliance on the clinical examination procedures to detect or rule out meniscus injuries may be imprudent, in light of the diagnostic accuracy of such procedures being reported as low as 29 to 59%. Experienced examiners using a modified McMurray's Test have been reported to have only moderate diagnostic accuracy in younger persons. Additionally, a history of trauma, often including a rotary mechanism, is a common attribute in the history as the degenerative tears later in life would be very unlikely. In addition to effusion, snapping and giving away are also common signs of meniscus injury. Thus, the history and subjective reports by the patient may be as informative as the clinical examination.

**IMAGING AND DIAGNOSIS**

Early clinical examination following acute knee trauma may have limited diagnostic value and MRI often reveals ACL injuries not initially detected. MRI is generally acknowledged to be the optimal imaging modality for identifying ligamentous, tendinous, cartilaginous surface, and subchondral bone injuries of the knee. Given the known propensity for meniscus and ACL injuries to be concurrent in a majority of skeletally immature athletes, suspicion of one injury should routinely include concern for concomitant injury. With a suggestive history or any clinical exam findings consistent with ACL or meniscus injury, diagnostic imaging is indicated to visualize the tissues suspected of involvement.

According to the American College of Radiology (ACR) Appropriateness Criteria, the topic of "Acute Trauma to the Knee" includes recommendations for persons of all ages (excluding infants). Within the rating system of the ACR Appropriateness Criteria are numerical scales pertaining to the most or least indicated imaging. The highest value of 9 is consistent with most indicated imaging and 1 is the lowest value or least indicated imaging. Among the variants listed for "Acute Trauma to the Knee," based on clinical presentation are two guidelines that may be applicable for individuals suspected of having ACL or meniscus injuries. Variant 2 of "Patient of any age (excluding infants); fall or twisting injury, with one or more of the following: focal tenderness, effusion, inability to bear weight - First study" recommends radiographs of the knee with a 9 rating followed by MRI at 5. This guideline is supplemented by Variant 3 or "Patient any age (excluding infants); fall or twisting injury with either no fracture or a Segond fracture seen on a radiograph, with one or more of the following: focal tenderness, effusion, inability to bear weight. Next study," which indicates MRI (without contrast) as being the preferred imaging with a rating of 9. Distinct from the tibial eminence fracture often occurring in young athletes, a Segond fracture is a small avulsion fracture often visualized along the lateral joint line on anterior-posterior view radiographs. This avulsion is usually of a small fragment of the middle third of the lateral tibial rim. While an atypical radiographic finding, Segond fractures are often associated with the presence of ACL injuries. Thus, the presence of such a finding on radiographs should raise suspicion of an ACL injury and indicates the need for MRI.

In the skeletally immature, overall MRI detection of ACL tears has been observed to demonstrate as high as 95% sensitivity and 88% specificity with arthroscopic exposure serving as the comparison standard. Other investigations have reported values as low as
64% to 78% sensitivity, while maintaining high specificity at 94% to 100%.\textsuperscript{22,23} The lower sensitivity reported in some investigations has been attributed to inexperience with assessment of the anatomy of that age group, difficulty with interpretation because of smaller and developmental anatomy, and the relatively higher proportion of incomplete tears in this age being more difficult to identify.\textsuperscript{16}

Injury patterns of the ACL may also vary considerably related to age. Tibial eminence avulsion fractures are most common during puberty, partial thickness tears among adolescents before skeletal maturity, and complete tears after skeletal maturity. While much attention has been focused on the ACL injury rate in female athletes, ACL injuries are also very common in young males during the period of open physes in the form of tibial eminence avulsions or incomplete tears. In a recent report of American high school sports injury data, ACL injuries accounted for 12.25% of all recorded injuries in male athletes.\textsuperscript{7} The predominance of female ACL injuries occurs later as skeletal maturation continues.\textsuperscript{13,24}

The accuracy of MRI results compared to intra-operative findings for meniscus tears for children and adolescent persons has been inconsistently reported. The accuracy of MRI in detecting meniscus tears in adolescents may be comparable to that in adults.\textsuperscript{13} Major et al\textsuperscript{2} evaluated individuals aged 11 to 17 years with a mean age of 15 and compared the results of MRI interpretations to those of adults. The results were similar across the age groups. The sensitivities to medial and lateral meniscus tears were calculated to be 92% and 93%, respectively, with specificities at 87% and 95%, respectively. Other investigations suggest less diagnostic accuracy in pediatric patients, probably because of the developmental changes present in the meniscus in those skeletally immature. Sensitivities as low as 50% to 62% have been reported with lower accuracy in those under age 12.\textsuperscript{9,16} The normally greater vascularity of the meniscus in children can cause enhancement within the mid-substance of the meniscus, thus, mimicking a tear and complicating the interpretation.\textsuperscript{17}

In addition to meniscal injury, the medial collateral ligament and edema are often seen in association with tears of the ACL because of the valgus stress of the pivot shift-like mechanism of trauma.\textsuperscript{14} Because of the potential for the history and the clinical examination of the patient to not correspond with the imaging findings as read by a radiologist, some orthopedic surgeons believe that the physician conducting the examination should also be the interpreter of the diagnostic imaging.\textsuperscript{25}

**SURGICAL DECISION MAKING**

Anterior cruciate ligament reconstruction and rehabilitation in skeletally immature athletes is more complex than in adults and those with closed physes. Trauma or orthopedic interventions may disrupt the physes and create bony bridges resulting in a reduction of bone length or angulation.\textsuperscript{26} The long bones of the knee account for approximately 65% of potential lower extremity growth as the distal femur accounts for 37% and the proximal tibia for 28%.\textsuperscript{27,28} The threat of injury to the growth plates of the femur and tibia resulting from the reconstructive procedure and subsequent life-long limb length discrepancy is particularly important in decision making for pediatric patients. For those sustaining injuries prior to the interval of maximum growth in early adolescence, the potential effect may be of even greater magnitude.

Among the factors considered by orthopedic surgeons in selecting the best reconstructive procedure for the pediatric or adolescent patient is the physiologic age and potential for growth. For the patient in this case report, radiographs were completed to establish his bone age (Figure 5). At the time of the completion of this radiograph, a bone age of eight years (96 months) was determined. His chronological age was actually eight years and seven months (103 months) or 1.4 standard deviations below the mean, but within normal limits (<2.0 standard deviations). This methodology of determining bone age was established by Greulich and Pyle and considers the pattern of epiphyses and bone development of the hand and wrist.\textsuperscript{29} The actual radiographs of the individual are compared in an atlas to those of established standards of bone development. Once established for the individual patient, the actual bone age must be a consideration in the choice of operative procedures to minimize the risk of growth disruption. The use of Tanner staging based on sexual
characteristics has also been employed by surgeons in order to classify their patients’ physiologic age for consideration prior to undergoing knee reconstruction procedures.30

The available surgical procedures for the skeletally immature patient who has sustained an ACL tear are generally categorized as physeal sparing, transphyseal, and partial transphyseal reconstructions.5 Conventional transphyseal tunnels for the graft anchors (as used in those with closed growth plates) have been described, but presumably contain the greatest risk of physis injury and growth disturbance. The extent of this risk, however, is not precisely known. Variations on these techniques in which only one physis is affected with the stabilization have also been reported.31 Theoretically, extra-articular reconstruction, sparing the physis, provides a method to restore joint stability and maximally avoid risk of growth disturbance. Extra-articular reconstructions, however, have a history of variable outcomes.5 The technique used in the young athlete in this report is a physeal sparing technique in which the bone tunnels for the hamstring graft were placed only through the femoral and tibial epiphyses.32

Some surgeons recommend the type of technique based on the child’s or adolescent’s physiologic or bone age. Chicorell et al5 recommend physeal-sparing combined intra-extra-articular reconstruction with ITB for the pre-pubescent patient at Tanner Stage 1 or 2 (Males: ≤12 years, Females: ≤11 years). For adolescents with growth remaining at Tanner Stage 2 or 3 (Males 13-16 years, Females 12-14 years), a transphyseal reconstruction using a hamstring graft and metaphyseal fixation is recommended. For Tanner stage 5 (Males >16 years, Females >14 years), an adult-type reconstruction with interference screw is recommended. This strategy is advocated to minimize threat of disruption of epiphysis and subsequent interference with growth potential. Similarly, other surgeons suggest the lower limit to perform an adult type ACL reconstruction in which the physis would likely be closed is over 14 years for females and over 16 years for males.33

In an anatomical study based upon 31 patients 10 to 15 years of age, Kercher et al34 determined that less than 3% injury occurs when drilling an 8-millimeter tunnel across the physis. They further proposed that a vertical tunnel has minimal effect, but the tunnel diameter is critical to minimize the magnitude of physis violation. Interference screws can be placed safely in order to avoid the physis, but require careful planning. Their work was similar in nature to that of other investigators who proposed that less than 7% in the frontal plane and 1% in the transverse plane of the femoral physes were affected as a result of a femoral only transphyseal procedure, presumably offering little risk for growth disturbance.31

Kennedy et al35 recently tested three simulated pediatric ACL reconstructions using six cadaveric specimens, evaluating for the magnitude of anterior tibial translation and the pivot shift. The all epiphyseal technique improved stability, but did not restore the

Figure 5. A posterior-anterior radiograph of the hand to establish the bone age of the patient.
knee to pre-injury ACL laxity as compared to the extra-physseal iliotibial band (ITB) technique. Greater residual laxity compared to the pre-injury state was present in the all epiphyseal and transtibial over-the-top techniques. The ITB technique, however, actually excessively constrained the rotational component of the knee motion compared to the intact status. Interpretation of these findings must be with caution because of the limited scope of the study.

In a meta-analysis derived from 55 published reports, Frosch et al\(^3\) determined the overall rate of significant limb length discrepancies or malalignment complications to be 1.8%. Transphysseal reconstruction was associated with a significantly lower risk of leg-length differences or varus-valgus deviations (1.9%) compared with physeal-sparing techniques (5.8%), but had a higher risk of re-rupture (4.2% vs. 1.4%). The authors of the meta-analysis offered the explanation of the technical challenges of the surgery and the fragility of the growth plate for the apparently counter-intuitive findings of the physeal sparing techniques having higher risk of leg length discrepancies. One must also consider the selection of physeal sparing procedures in younger patients with inherently greater risk of growth disturbance because of their age. The collective data also suggested bone-patellar tendon-bone grafts are less likely to fail, but had higher risks of leg-length differences and varus-valgus deviations than the hamstrings grafts (3.6% vs. 2.0%). A critical analysis must also include acknowledgment that direct comparisons of techniques in clinical trials have not yet occurred. Thus, no single technique has been determined to be clinically superior, in part because all reported data are in small case series with only short-term follow-up.\(^3\) Direct comparison studies of the techniques with long-term outcomes will be required to determine if one technique yields best results.

**INTERVENTION**

Approximately eight weeks following the injury, the young athlete underwent surgical reconstruction of his right knee. The intra-operative findings were consistent with the imaging and clinical examination findings. The ACL was observed to be completely ruptured and had markedly atrophied in the two month interval between injury and surgery (Figure 5). The suspected lateral meniscus tear was also confirmed to be present (Figure 6). An all epiphyseal technique was completed to reconstruct his right ACL using a quadruple hamstring graft comprised of the semitendinosus and gracilis tendons (Figure 7). The unstable intrasubstance tear of the lateral meniscus was repaired using an inside-out technique (Figure 8). The articular cartilage of his tibiofemoral joint was explored during the surgical exposure and was found to be normal. The ACL reconstruction along with the meniscus repair, although technically challenging, were completed without complication, according to the surgeon’s report. Dr. Allen F. Anderson MD (Nashville, TN) has provided the video of the surgical procedure used for the subject of this case report. The link to this video is available at www.ijspt.org and the authors invite you view the surgery to expand your understanding of this complex procedure.

Post-operative care and the rehabilitative progression for the skeletally immature athlete are similar to that of adults undergoing other grafting procedures, albeit with greater initial precautions and a
more conservative progression. The rehabilitative protocol for this patient, as preferred by the orthopedic surgeon, required an immediate post-operative period of non-weight-bearing for six weeks for protection of the epiphyses (with bone tunnels) and meniscus repair while working on recovery of knee range of motion and muscle activation throughout the affected lower extremity. He initiated formal physical therapy the day of the surgery while still in the hospital and continued with regular supervised outpatient visits the same week, while also completing multiple exercises at home under the supervision of his parents. He began progression to weight-bearing activities at six weeks post-operatively and discontinued using crutches after 12 weeks. He completed a total of 29 physical therapy visits over a seven month period, fully recovering his range of motion, regaining his strength, and demonstrating only minimal residual quadriceps atrophy. At approximately eight months after surgery, the treating therapist compared the athlete's involved lower extremity to the uninvolved with multiple functional tests, including the single leg hop for distance, single leg vertical jump, triple hop for distance, and single leg diagonal hop for distance. He was judged by the therapist to have comparable function in the involved lower extremity. Circumferential thigh measures indicated the affected limb to have only minor remaining atrophy. Clearance for return to participation in sports occurred one month later during a follow-up visit to the orthopedic surgeon. While approved to return to high level activities by the physician, wear of a protective brace for one to two years was recommended.

The specific rehabilitation procedures and his progression are not the focus of this report. Greenberg et al. have provided details of a similar post-operative rehabilitation protocol used in their case report.
describing an eight year-old having also undergone an all epiphyseal ACL reconstruction. The authors discuss criteria for return to participation and functional testing. Readers are referred to the Greenberg et al paper for specific details on the rehabilitation progression in that young athlete and decision making for return to sports participation.

During the course of rehabilitation of the young athlete described in this case report, follow-up visits were completed with his orthopedic surgeon. Radiographs were obtained during these visits to assess for hardware integrity, the continued presence of open physes, and any suggestion of developing varus or valgus angulation or other malalignment. Figures 10 and 11 are examples of the follow-up radiographs completed to monitor his progress, taken nine months post-operatively in this instance. Note the presence of the bone tunnels in the epiphyses and the open epiphyses in both the tibia and femur. More sophisticated imaging is usually reserved for individuals in whom knee radiographs indicate the need for further investigation, the clinical examination suggests angulation or asymmetry, or individuals who are having complications or functional impairments attributable to the involved knee. Should additional imaging be indicated, MRI would likely be chosen to further investigate the knee. MRI can evaluate in more detail than plain radiographs, the integrity of the graft, hardware loosening, and post-operative complications, including ganglion cyst formation, graft impingement, and arthrofibrosis. MRI may also give greater detail as to the possible presence of bony bridges spanning the physes. MRI can also demonstrate fluid characteristics within the joint, allow visualization of synovial hypertrophy, and reveal intra-articular loose bodies.
OUTCOME
That autumn, nine months following the surgery and only a few weeks after being cleared by the physician, the young athlete, then nine years of age, returned to playing football. He initially completed non-contact football training drills and gradually increased his activity level toward that demanded in practice and games. With his return to higher level activities, he wore a brace specifically for protection of knee and the ACL graft. The use of a brace intended to protect the reconstructed knee during sports activities has been advocated for one to two years following reconstruction in skeletally immature athletes. Although there are no outcome studies for the use of bracing specifically in pediatric or adolescent patients having had reconstructive procedures, the benefits may include improved proprioception and greater confidence. He also returned to participation in basketball in the winter and baseball the following spring and summer. He is currently playing successfully in his second season of football since the reconstructive procedure and rehabilitation. He continues to wear a supportive brace with this activity, now his second because of growth. His mother reports that he is experiencing no symptoms and is having no difficulty with the involved knee during participation in sports or other activities. His only complaint is mild tenderness with direct pressure over the tibial screw site (see Figures 10 and 11 for location). Although specific radiographic measures have not been undertaken to examine for overall limb length, there are no indications for suspicion of limb length inequality based on the post-operative knee radiographs or observations of impairment of functional performance.

RECOMMENDATIONS FOR THE FUTURE
Clinicians evaluating skeletally immature patients with traumatic onset of knee pain must be aware of the injury patterns that occur in pediatric and adolescent athletes. Practitioners must also be knowledgeable of the limitations of routinely used clinical examination procedures for suspected pathologies of the anterior cruciate ligament and menisci, particularly in younger individuals. Indications for imaging coupled with an understanding of the most appropriate imaging based on the patient’s presentation is also required. While those involved with the care of pediatric and adolescent athletes having undergone reconstructive knee procedures must obviously have expertise in the rehabilitation process, an understanding of the pre-operative and post-operative medical management of such patients may allow for improved care by a greater comprehension of the patient’s experiences and the decisions required by the parents and the physicians during the entire sequence of events prior to rehabilitation.

REFERENCES


ABSTRACT

Over the last decade, participation in organized youth sports has risen to include over 35 million contestants. The rise in participation has brought about an associated increase in both traumatic and overuse injuries in the youth athlete, which refers to both children and adolescents within a general age range of seven to 17. Exposure rates alone do not account for the increase in injuries. Societal pressures to perform at high levels affect both coaches and athletes and lead to inappropriate levels of training intensity, frequency, and duration. In this environment high physiologic stresses are applied to the immature skeleton of the youth athlete causing injury. Typically, since bone is the weakest link in the incomplete ossified skeleton, the majority of traumatic injuries result in fractures that occur both at mid-shaft and at the growth centers of bone. The following clinical commentary describes the common traumatic sports injuries that occur in youth athletes, as well as those which require rapid identification and care in order to prevent long term sequelae.

Key Words: Emergency care, immature skeleton, traumatic injuries, youth sports injuries

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INTRODUCTION
Injuries in sports account for about twenty-five percent of all childhood injuries. According to Safe Kids USA greater than 3.5 million athletes 14 years and younger receive medical care for sports related injuries. Youth athletes account for forty percent of all sports related injuries evaluated in the emergency department. An estimated 2.6 million emergency department visits per year involve athletes between the ages of five and 24. With the prevalence of injury in youth athletes, sports medicine practitioners need to understand, recognize, and correctly manage common injuries encountered by children who participate in sports. This knowledge can enhance youth athletics by minimizing injury severity, prolonged sequelae, and time away from sports, all of which can help to reduce sports attrition.

INJURIES TO IMMATURE BONE WHILE GROWING
The physiologic differences between children and adults account for the variation in differential diagnoses that exist in these two groups. Structurally, a child's bones are composed of more collagen and cartilage than the ossified bones of adults. During early childhood bones are weaker than their associated ligaments and tendons. Stresses placed across these structures produce bone failure and resultant fractures in children and adolescents, rather than soft tissue damage seen in the adult. Increased vascularity and a thickened periosteum in immature bone account for faster healing times and better capacity for remodeling, present in younger children as compared to adults. During the healing process, children typically do not encounter the complications of fracture nonunion and joint stiffness as do their adult counterparts. If properly managed they can heal without sequelae and quickly return to a normal active lifestyle.

The presence of the physis, referred to as the growth plate, is the most significant anatomical difference between children and adults. The physis is located at the distal portion of long bones and is comprised of cartilage, which allows the bones to expand and lengthen until completely ossified when the adolescent reaches skeletal maturity. Physeal centers close from distal to proximal with the last being the clavicle which may remain open into a person's early twenties. Prior to closure, while in the cartilaginous state, the physis is prone to failure with abnormal traumatic or chronic stress. The growth plate is the weakest link in the immature skeleton and when injured, can exhibit complete growth arrest, be impaired partially, or develop normally. The potential for growth disturbance makes identifying and appropriately managing a physeal injury a high priority.

PHYSEAL FRACTURES
By the age of 16, 42% of boys and 27% of girls will have incurred a fracture. Physeal (growth plate) fractures represent 6-30% of all childhood fractures. Growth arrest occurs in 15% of those growth plate injuries. Risk factors that impact growth arrest include the severity of injury, age, skeletal maturity, and anatomic site. Growth disturbance is the result of a premature bone bridge that forms vertically across the physis connecting the metaphysis and epiphysis. This occurs more commonly in the distal physes of the lower extremity as these physes are multiplanar. Magnetic resonance imaging (MRI) is useful in determining the size and location of the transphyseal bridge. Surgical resection of a transphyseal bridge that occupies 50% or less of the total physeal area, produces good clinical outcomes by allowing continued bone growth. Clinical presentations of growth disturbances are limb length discrepancy or angular deformity. In order to minimize and attempt to prevent growth plate disruption, the goal of fracture management is anatomic reduction and fracture stabilization until complete healing occurs.

The Salter-Harris Classification system is a standard descriptive system in the literature that identifies growth plate fractures according to their fracture line pattern and location. All youth who sustain growth plate fractures are at risk for growth disturbances, however, the more involved types of fractures present the greatest risk. Figure 1 displays Salter-Harris classifications I-V. Note the italicized words are additional descriptors and not a part of the standard classification. Salter-Harris type V fractures are difficult to initially diagnose and are identified after growth asymmetry is noted. These injuries are rare and are most typically the result of high velocity accidents like motor vehicle accident (MVA) or a fall from a substantial height. All growth plate fractures have the potential for growth arrest, and...
therefore require monitoring at 6 months and one year post fracture. Figure 2 displays warning signs presented by young athletes with fractures.

**UPPER EXTREMITY**

Injuries to the upper extremity are commonly sustained by children. Often a fall on an outstretched hand (FOOSH) is the mechanism of injury for many fractures that occur throughout the upper extremity. Clavicle fractures represent four percent of all fractures and are common in children and adolescents under the age of 25. The majority of these fractures occur within the midshaft of the clavicle and are the result of a direct blow to the lateral aspect of the shoulder. The athlete will present with a painful palpable defect and localized swelling over the clavicle. Shoulder exam reveals pain on shoulder elevation and horizontal adduction. The majority are treated non-operatively with a “Figure 8” harness or arm sling for two to four weeks. Conservative management is typically successful, however most heal with a shortened length (malunion) and permanent bump. Surgery after clavicular fracture, although infrequent, is indicated after an open fracture, tenting of skin, neurovascular compromise, or a comminuted fracture.

Traumatic anterior glenohumeral dislocations are common in the adolescent but uncommon in the skeletally immature athlete. The noted mechanism of injury for an anterior dislocation is an indirect blow to the arm positioned in abduction, external rotation and extension. After dislocation, the athlete may position the injured arm in internal rotation with the inability to externally rotate. A transient loss of sensation or numbness to the upper extremity may also be present. Several methods of closed reduction are explained in sports medicine literature with traction of the upper extremity being a major component. In the youth athlete, closed reduction is preferred to take place in an emergency care facility where pre- and post-reduction radiographs can be taken to ensure a humeral head fracture has not occurred. The neurovascular status of the involved upper extremity needs to be evaluated pre- and post-reduction as well. A Hill Sachs lesion is an impression fracture of the posterior lateral aspect of the humeral head and often occurs during dislocation as the humeral head comes into forceful contact with the glenoid rim. Post reduction protocols vary in time and position according to physician preference, however most recommend immobilization from one

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<tr>
<td>I</td>
<td>Fracture lines extend through the physisal plate—<em>Growth arrest uncommon</em></td>
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<tr>
<td>II</td>
<td>Fracture lines extend through the physisal plate and metaphysis—<em>May or may not cause growth arrest. Outcomes favorable</em></td>
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<td>III</td>
<td>Fracture line extends from the joint surface through the epiphysis and across the physis causing a portion of the epiphysis to become displaced—<em>Growth arrest likely, often require open reduction internal fixation, an intra-articular injury</em></td>
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<tr>
<td>IV</td>
<td>Fracture line extends from joint surface through the epiphysis, physisal plate and metaphysis causing a fracture fragment—<em>Growth arrest likely, almost always require open reduction internal fixation, an intra-articular injury</em></td>
</tr>
<tr>
<td>V</td>
<td>Crush injury to the growth plate, not identified until after growth arrest has occurred (6-12 mos)—<em>Rare, growth arrest certain, poor outcomes</em></td>
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**Figure 1.** *Salter-Harris classification system for pediatric fractures.*

**Figure 2.** *Common presentation in pediatric athletes with fractures.*
to six weeks.\textsuperscript{10,11,12} Gentle and gradual range of motion is initiated after the immobilization period. Complications of anterior shoulder dislocations include: a Hill Sachs lesion, a Bankart lesion, and high re-occurrence rates in athletes under the age of 20.\textsuperscript{10,11} Posterior shoulder dislocations occur much less frequently and are the result of trauma to an adducted internally rotated shoulder during a FOOSH injury, a posteriorly directed blow to the humerus, or forced glenohumeral elevation with adduction and internal rotation.\textsuperscript{10}

Proximal humeral fractures are not very common, and account for less than five percent of physeal fractures.\textsuperscript{11,12} In the five to ten year old age group, transverse metaphyseal fractures are more common whereas children older than 11 years of age more commonly acquire Salter Harris Type II fractures of the proximal humerus.\textsuperscript{11,12} The peak incidence of this injury is at age 15.\textsuperscript{12} Radiograph sequences of anterior/posterior (AP), axillary, and Stryker notch views are taken and compared to the non-injured contralateral side. High resolution MRI is the imaging modality of choice to detect subtle growth plate disturbances.\textsuperscript{12} Additionally, imaging is used to rule out unicameral bone cysts and bone tumors which occur rarely, but if missed, can lead to delay in appropriate treatment.\textsuperscript{11,12} Non-operative treatment produces excellent results, although a one to three centimeter limb shortening is commonly noted as a result of premature growth plate closure.\textsuperscript{11} Operative treatment is indicated for large displacements, irreducible fractures, or fractures of the greater or lesser tuberosity.\textsuperscript{11,12}

**Elbow injuries**

Many traumatic injuries about the elbow are the result of the distal humeral growth centers being weaker than the stabilizing ligaments.\textsuperscript{13} Acute elbow injuries include supracondylar fractures, distal humeral physeal fractures, avulsion fractures of the medial epicondyle and the olecranon. Supracondylar fractures are the most common elbow fracture sustained by children younger than ten and can be severe and have accompanying neurovascular complications which can result in permanent limb loss or dysfunction.\textsuperscript{6,10} They contribute to greater than fifty percent of all elbow fractures.\textsuperscript{10} The vast majority of supracondylar fractures are extension type and often the result of a FOOSH injury with the elbow in full extension or hyperextension causing the olecranon to wedge into the olecranon fossa disrupting the anterior cortex.\textsuperscript{6,10} The child presents with swelling, localized pain, tenderness, and depression over the triceps area.\textsuperscript{6,10} Extensive swelling, ecchymosis and puckering of the skin, indicates the seriousness of the injury and presents an increased risk for forearm compartment syndrome which is an emergent condition that requires a surgical fasciotomy to restore circulation to the tissues.\textsuperscript{6,10} Signs of compartment syndrome include: increased pain on passive finger extension, loss of color in hand, numbness, tingling, loss of motion, and decreased radial pulse. In addition to checking for signs of compartment syndrome, a thorough neurovascular exam which addresses the integrity of the brachial artery, median, and radial nerves should be performed. If the child can perform the “OK” sign by flexing the thumb and distal phalanx of the index finger then the median nerve is intact. Impaired active wrist extension may indicate radial nerve compromise. Treatment includes surgical reduction and internal fixation within twenty-four hours if the fracture is severe.\textsuperscript{6} Circulation to the hand is monitored after surgery. Additional complications include neuropraxia, brachial artery compromise, Volkmann's Ischemia (claw-like deformity of the hand as the result of contracted forearm muscles due to ischemia) and loss of motion.\textsuperscript{5,10} Flexion type supracondylar fractures, which occur infrequently, are the result of a fall onto a flexed elbow with the ulnar nerve most commonly involved.\textsuperscript{5,10}

In children, distal humeral lateral condyle fractures are the second most common fracture of the elbow region.\textsuperscript{6} It is typically caused by a FOOSH injury with a varus force which produces an avulsion fracture or by a compression force to the capitellum by the radial head. Evaluation includes radiographs with comparison views of anterior-posterior (AP) and lateral elbow. Additionally, oblique views are utilized as they often show the greatest fracture displacement.\textsuperscript{6} Clinically, an elevated fat pad is considered a positive fat pad sign and has 70% accuracy in identifying a fracture. Hemarthrosis may be present as well.\textsuperscript{6} Due to the nature of the injury, most are treated surgically unless the degree of fracture
displacement is less than two millimeters. Greater than two millimeters of displacement requires surgical fixation under fluoroscopy.

Elbow dislocations are more common among 13 and 14 year old athletes when the distal physis begins to close. They rarely occur in younger athletes, who are more likely to sustain a fracture. The mechanism of injury is a forced axial load with the elbow in hyper-extension and valgus positioning with or without an external rotation moment. Physical exam identifies swelling and deformity around the elbow with the look of apparent forearm shortening possible. Radiographs are necessary to confirm diagnosis and rule out associated fractures. Isolated elbow dislocations are rare and an avulsion of the medial epicondyle is common. Non-operative treatment includes closed reduction under conscious sedation followed by immobilization in a posterior splint with the elbow flexed at ninety degrees. A neurological exam determining the integrity of the brachial artery and median nerve is performed pre- and post-reduction. Active range of motion is initiated after two weeks of immobilization to avoid a flexion contracture and loss of terminal elbow extension. Surgical management is indicated if there is an inability to achieve closed reduction, or in the presence of an open fracture or an osteochondral fracture.

A medial epicondyle avulsion fracture is most often seen in teenage boys, and is sustained during late cocking and acceleration phases of throwing where a valgus stress and forceful contraction of the flexor pronator group places excessive forces across the elbow. It occurs during a one time throw where a “pop” is often heard or felt in the medial elbow. Physical exam reveals point tenderness over the medial epicondyle, swelling, ecchymosis, and questionable instability. Comparison views of AP and lateral radiographs are used to identify the amount of displacement of the medial epicondyle. Radiographic findings are more subtle in the younger athlete due to the lack of ossification of the medial epicondyle at that age. Treatment of medial epicondyle fractures depends upon the size and displacement of the fracture, associated valgus instability, and presence of ulnar nerve symptoms. Non-surgical treatment parameters are minimal to no displacement, absence of valgus instability, and no ulnar nerve involvement. Treatment of medial epicondyle avulsion fractures consists of cast immobilization for 3 weeks with the elbow flexed at ninety degrees. Early motion to avoid loss of elbow extension is implemented post casting. Flexor pronator strengthening is initiated once the athlete is pain free. A return to throwing program is initiated when radiographic union is observed in a pain free elbow and full ROM and strength has been restored. Surgery is indicated if the avulsed fracture fragment is displaced greater than five millimeters.

In older adolescents who are acquiring strength and power, an avulsion fracture of the olecranon can be sustained during the acceleration and follow through phases of throwing. Subjective history indicates an acute onset of posterior elbow pain with a loss of full elbow extension. Pain on palpation over the tip of the olecranon, swelling and ecchymosis posteriorly, painful loss of elbow extension, and weakness of the triceps are all observed on physical exam. Surgical reattachment of the extensor mechanism is required.

**Wrist and Hand**

Hand and wrist injuries are some of the most common injuries that occur in athletes of all sports and the young athlete is no exception. In collision sports such as football, hand injuries account for 15% of all injuries. Wrist sprains are very rare and a fracture should be suspected if there is post traumatic wrist swelling. Forty-six to 80% of gymnasts suffer injuries to the wrist. Hand fractures increase sharply after the age of eight and peak around 13 years of age. A hand specialist optimally manages these injuries as they can be complicated by trauma to multiple small structures with a potential combination of fractures, dislocations, as well as capsular and ligamentous injuries. Evaluation of hand injuries includes both passive and active ROM of all digits, varus and valgus stress tests about each joint, and assessment of volar plate integrity with hyperextension testing. A quick screen for hand pathology is to have the athlete attempt to make a closed fist. In an uninjured hand all nail beds are parallel, the hand closes easily without pain and all finger tips point to the scaphoid tubercle. The long and detailed list of athletic wrist and hand injuries is beyond the scope of this clinical commentary, however one injury
worth mentioning is the scaphoid fracture, which comprises 70% of all carpal fractures.14 Fifteen to 30 year olds are most typically affected.14 A complicated vascular anatomy accounts for high rates of malunion and nonunion that occur post scaphoid fracture. A scaphoid fracture must be suspected in any athlete who participates in a contact sport and complains of radial wrist pain, pain in the anatomical snuff box, decreased ROM, swelling, and pain with extension of the wrist and hand.14 Initial radiographs often do not identify the fracture, therefore if there is a high suspicion of scaphoid injury, an MRI should be obtained. The goal of treatment is to obtain fracture union. Surgical or non-surgical treatment is determined on a case by case basis depending on the location and stability of the fracture, the athlete's sport, and the goals of the athlete. Options include cast immobilization without participation in sports, cast immobilization and a playing cast for sports participation or surgical treatment.14 Average healing for cast immobilization is eight to ten weeks.14 The complications of delayed union or nonunion are observed in athletes where initial management of the injury was not optimal, thus it is imperative that the sports physical therapist does not miss this diagnosis.

Due to the common occurrence of upper extremity injuries in the young athlete, sports medicine practitioners need to have available appropriate supplies for emergency management of traumatic injuries of the upper extremity on the sidelines. Medical kit supplies include, but are not limited to, smaller widths of tape and ace bandages, small size wrist splints, and a SAM® splint that can be molded as appropriate. Multiple triangular or elastic bandages are necessary to use for splint immobilization, securing an injured upper extremity to the body, or as a sling or swath. Figure 3 offers guidelines on upper extremity injury prevention.

**LOWER EXTREMITY**

Evaluation of the acutely limping youth and adolescent athlete presents many challenges to the sports medicine practitioner. In addition to the numerous possible lower extremity growth plate fractures, underlying joint pathology needs to be ruled out as a cause for a painful limp and/or a Trendelenburg gait.16,17 Referred pain patterns from organ systems and the thigh can lead to confusing presentations. When the acute injury is not obvious or visualized, a thorough lower extremity exam of the hip and knee is warranted. Subjective information should include recent illness, weight loss, night sweats or fever, hearing or feeling a “pop” and determining if the patient can localize the pain or point of maximum tenderness with one finger. During the physical exam, ROM restrictions and asymmetries are noted as well as painful provocation motions. Sideline or clinical management of an acutely limping athlete who is having difficulty weight bearing requires a rapid referral to an orthopedic or sports medicine specialist with the athlete placed on protective weight bearing using crutches or a wheelchair until evaluation is

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1. Limit onset of teaching of difficult pitches
2. Use of a smaller youth sized baseball
3. Optimize technique/throwing mechanics
4. Insure appropriate strength and conditioning of arms, shoulders, core and legs
5. Limit number of pitches
6. Recognize total volume of throwing (multiple leagues/teams, free play)
7. Recognize that unconditioned athletes tend to have poor mechanics
8. Recognize that highly conditioned athletes are predisposed to exceed the limits of the musculoskeletal system
   • Detailed pitching recommendations can be found on the USA Baseball Medical and Safety Advisory Committee Guidelines webpage
   [http://www.asmi.org/asmiweb/usabaseball.htm](http://www.asmi.org/asmiweb/usabaseball.htm)

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**Figure 3. Upper extremity injury prevention strategies.**
completed. AP, lateral and frog radiographs of the hip joint are warranted if ROM limitations, decreased lower extremity weight bearing, painful joints and/or point tenderness are discovered.9,17,18 Hip joint pathology can present as thigh or knee pain. The age of the athlete can assist in differential diagnosis. Refer to Table 1 for age related diagnosis and physical presentations.17,18 Transient synovitis, Legg-Calve Perthes and Slipped Capital Femoral Epiphysis (SCFE), are a few of the more common non-sports related pathologies that are encountered by the youth athlete. Though not truly acute injuries related to

<table>
<thead>
<tr>
<th>Age</th>
<th>Diagnosis</th>
<th>History</th>
<th>Physical Exam</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-10</td>
<td>Legg-Calve-Perthes</td>
<td>Limp with hip or knee pain, insidious onset (1 to 3 mos)</td>
<td>Limited hip abduction, flexion, and internal rotation</td>
</tr>
<tr>
<td></td>
<td>Transient Synovitis</td>
<td>Fever, chills, erythema, pain</td>
<td>Trendelenburg gait, stiffness, guarding of movements</td>
</tr>
<tr>
<td>11-16</td>
<td>Slipped Capital Femoral Epiphysis (SCFE)</td>
<td>Hip pain, referred pain to anterior thigh or knee. Acute or chronic</td>
<td>Pain, limited internal rotation. Position of comfort hip flexion, abduction</td>
</tr>
<tr>
<td></td>
<td>Avascular Necrosis of Femoral head</td>
<td>presentation</td>
<td>and external rotation.</td>
</tr>
<tr>
<td></td>
<td>Femoral Neck Stress Fracture</td>
<td>Pain in groin, lateral hip and buttock. History of steroid use, prior</td>
<td>Pain with ambulation, hip abduction, internal and external rotation</td>
</tr>
<tr>
<td></td>
<td>Hip Pointer</td>
<td>fracture or SCFE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Avulsion fractures</td>
<td>endurance athlete, female athlete triad. Pain increases with weight</td>
<td>Pain on palpation over greater trochanter, painful ROM, positive single leg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>bearing and impact. Groin pain</td>
<td>hip test</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct trauma to iliac crest</td>
<td>Pain on palpation, painful ambulation and active hip abduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>sudden forceful muscle contraction or stretch. May hear/feel “pop”</td>
<td>Pain over involved apophysis. Pain on PROM or resisted muscle activity.</td>
</tr>
<tr>
<td>All Ages</td>
<td>Septic Arthritis</td>
<td>Chills, fatigue, fever</td>
<td>Decreased ROM, Pain with limb movement and Internal rotation, swelling,</td>
</tr>
<tr>
<td></td>
<td>Osteomyelitis (bone infection)</td>
<td>Fever, chills, irritability, fatigue. Develops rapidly over 7 to 10 days</td>
<td>warmth. Preferred position: flexion, abduction, and external rotation.</td>
</tr>
<tr>
<td></td>
<td>Neoplasms</td>
<td>Night pain, pain that wakes the child up, pain unrelated to activity</td>
<td>Pain/tenderness over hip joint, pain with movement, difficulty weight</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>bearing</td>
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</table>
sport, these conditions may present with a sudden limp due to an increase in symptoms due to the underlying pathology.

Avulsion fractures about the pelvis are prevalent in the older adolescent as the last growth centers begin to ossify between the ages of 14 and 25. The growth centers at the anterior superior iliac spine (ASIS) and the ischial tuberosity are the last to close in the pelvis and can remain open until 25 years of age. The fractures occur at the sites of ligament or tendon insertions, referred to as the apophysis, and are caused by a sudden, powerful muscle contraction or stretch which produces high traction loads across the interface. Common sites include the (ASIS), anterior inferior iliac spine (AIIS), iliac crest, ischial tuberosity and lesser trochanter. Athletes who participate in running, gymnastics and football are predisposed due to the musculoskeletal requirements of their sport. The softer, cartilagenous osseous structure is pulled away from the immature bone. A pop is felt at the injury site followed by intense pain. Point tenderness over the avulsion site with swelling, weakness and difficulty weight bearing are frequently noted. Table 2 provides details regarding the specific types of avulsion fractures (apophyseal injuries) throughout the pelvis. These injuries are often misdiagnosed as a muscle strain, particularly ischial tuberosity avulsions, which are commonly viewed as hamstring injuries. Avulsion fractures are most commonly diagnosed by radiographs, and the displaced bone is visible. Follow up radiographs illustrate new bone formation. Treatment is conservative and surgery is rarely indicated as most fractures are minimally displaced. If greater than two millimeters of displacement occurs then surgery is recommended. Rest, ice, compression, elevation (RICE), immobilization and protective weight bearing are implemented. Limiting stress and traction across the apophysis are initial goals of treatment. Timeframes of return to sport can be prolonged depending upon the severity and location of the avulsion. Protective weight bearing continues until callus formation is noted on radiographs.

A hip pointer injury is different from an avulsion fracture and is due to direct trauma to the iliac crest by a fall or collision. Point tenderness at the injury

<table>
<thead>
<tr>
<th>Site</th>
<th>Associated Muscles</th>
<th>Mechanism of Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASIS</td>
<td>Sartorius</td>
<td>Passive hip extension coupled with knee flexion or active hip flexion coupled with knee extension</td>
</tr>
<tr>
<td>AIIS</td>
<td>Rectus Femoris</td>
<td>Sudden contraction of Rectus Femoris such as with a vigorous kick</td>
</tr>
<tr>
<td>Ischial Tuberosity</td>
<td>Hamstrings and Adductor Magnus</td>
<td>Passive hip flexion coupled with knee extension or active hip extension coupled with knee flexion</td>
</tr>
<tr>
<td>Lesser Trochanter</td>
<td>Iliopsoas</td>
<td>Sudden active hip flexion</td>
</tr>
<tr>
<td>Iliac Crest</td>
<td>Abdominal Obliques</td>
<td>Sudden contraction of Obliques</td>
</tr>
</tbody>
</table>
site is palpated on the iliac crest. Pain is reported during ambulation and with hip abduction. Treatment includes RICE, activity modification and gradual return to sport when the athlete can perform activities without a limp and the sports PT has devised padded protection of the of the injured area.

Femoral neck stress fractures, although not acute in nature, can progress to an emergent condition in which swift and appropriate care is necessary. These injuries are common in distance runners, especially females, who are notorious for under reporting pain until limping and difficulty weight bearing becomes noteworthy. The adolescent athlete may present with pain radiating into the groin, thigh, knee, or over the greater trochanter and an increase pain with hip ROM's of flexion and internal rotation, during weight bearing and the single leg hop test. Pain is exacerbated by impact activities and in later stages continues at rest and at night. Subjective examination reveals a change in duration, intensity, or frequency of activity which occurred 2 to 5 weeks prior to the onset of symptoms. Radiographs are often negative early and an MRI is required for diagnosis if there is a high suspicion for stress fracture. MRI is the imaging modality of choice for monitoring healing of femoral neck stress fractures. Due to the high risk of complications which accompany a femoral neck stress fracture if mismanaged for too long, swift and accurate diagnosis is crucial. Complications include avascular necrosis of the femoral head, and delayed union and/or nonunion of the fracture. Prognosis is based on location and the extent of the stress fracture. Three classifications of femoral neck stress fractures include compression side (inferior medial aspect of femoral neck), tension side (superior lateral aspect of femoral neck) and displaced which is a complete fracture of the femoral neck. Treatment for tension side non-displaced fractures is rest, non-weight bearing, with crutches or a wheelchair depending on pain level until imaging demonstrates healing. At that time slow progressive pain-free weight bearing is permitted with gradual return to activity monitored by a sports rehabilitation professional. Surgical stabilization is required for a tension side fracture to prevent progression. A displaced femoral neck fracture is an orthopedic emergency requiring immediate surgical fixation.

Knee Injuries

Although the mechanism of injury for traumatic disorders of the knee for the youth athlete often is similar to the skeletally mature athlete, the diagnosis can be vastly different. In the skeletally immature athlete, the evaluating clinician needs to have a high suspicion for an avulsion fracture or growth plate injury versus a ligamentous strain or tear. Traumatic knee injuries unique to the immature athlete include tibial spine avulsion fractures and medial distal femoral physeal fractures. Additionally, pathologic fractures can occur during play due to areas of bone weakness caused by underlying pathologies such as a malignant neoplasm, unicameral bone cyst, or an underlying metabolic disorder. Tibial spine avulsion fractures are seen in youth athletes between the ages of eight and 14 when the incomplete ossified tibial spine fails due to excessive stress placed on the anterior cruciate ligament (ACL) that attaches there. During this type of injury, the attenuate but intact ACL pulls on the tibial spine causing an avulsion fracture as well as potential concomitant collateral ligament and meniscal involvement. The mechanism of injury is similar to an ACL rupture with valgus and rotational stresses placed upon the knee while in extension. Acutely, the athlete presents with a large effusion, positive anterior drawer, pain on palpation, pain with movements, and decreased weight bearing. Loss of motion can occur due to mechanical impingement of the fracture fragment. Imaging includes AP and lateral radiographs with comparison views and MRI to identify bone and soft tissue involvement as well as to determine the amount of tibial spine displacement. Classification into four types of tibial spine fractures assists in developing treatment protocols. The goal is anatomic reduction which may be achieved by simple cylindrical casting in knee extension or require surgical fixation depending on the amount of displacement of the tibial spine and the involvement of other structures. Types of tibial spine avulsion fractures include: I-nondisplaced, II-partially attached, III- displaced and IV-communuted. Acute management calls for immobilization in the position found and transportation to the emergency department with an evaluation by an orthopedic surgeon. In general, treatment results are good with non-union being rare. Long term outcomes illustrate asymptomatic residual laxity which does not improve
with growth or age and is noted on exam only.\textsuperscript{9,19,23} Rarely is subjective laxity reported by the athlete.\textsuperscript{9,19,23} Complications include loss of motion due to arthrofibrosis, malunion, and physeal growth disturbance.

As the incidence rises for traumatic knee injuries for the young athlete, so has the overall number of ACL tears.\textsuperscript{22} Both the lachman and anterior drawer tests are utilized for evaluating an ACL injury in the younger population.\textsuperscript{1,9,22} In the younger athlete with wide open physes, boys acquire more ACL tears than females, however with growth and skeletal maturity, female athletes surpass their male counterparts with increasingly higher ACL injury rates.\textsuperscript{1} Deciding to repair the ACL while growth plates are open is done on an individual basis. The child and the parent must consider the risk of growth disturbances even with a physeal sparing procedure versus the potential for additional damage or injury to the knee if the child is unable or unwilling to scale back high demand impact and pivoting sports.\textsuperscript{1,7,22} In order to maximize outcomes and minimize risk, selecting a surgeon who specializes in pediatric sports medicine and physeal sparing procedures is crucial. If the athlete is willing to modify his/her activity level, and delay surgery until the growth plates are approximating, rehabilitation to improve secondary constraints through proprioception and strengthening is implemented.\textsuperscript{22} The use of a hinged brace for low demand activities may be an option depending on the sport and the physician’s individual preference.

Although medial distal femoral physis fractures account for less than one percent of all pediatric fractures, complications are frequently observed. Since the growth plates about the knee are the largest and fastest growing in the body, growth plate disturbances can cause angular deformity, leg length inequality, joint stiffness and acute neurovascular injury.\textsuperscript{19,20} Similar to a medial collateral ligament injury (MCL) in the mature skeletal athlete, a valgus stress with the knee in an extended position causes injury to the medial structures of the knee. (Figure 4) (Figure 5) The softer, distal femoral physis fails as the tension from the stretched MCL pulls at the insertion of the distal epiphysis of the femur causing a physeal fracture.\textsuperscript{20} Physical exam indicates pain with valgus stress, possible medial instability or laxity, pain on palpation over the medial femoral phy-
sis and possibly over the MCL. Salter-Harris Type I fractures often present with negative radiographs and require a MRI evaluation to identify the separation of the physis. These fractures are treated with cast immobilization and non-weight bearing for two weeks with repeat radiographs to demonstrate healing prior to progression off crutches. The most common Salter-Harris fracture is Type II in which the fracture line crosses the physis and exits the joint region obliquely across the medial corner of the metaphysis. Non displaced Type II fractures are treated with non weight bearing as well and cast immobilization for four to six weeks. Serial radiographs are taken to ensure healing without fracture displacement and angulation. Type I and II displaced fractures require reduction under anesthesia. Salter–Harris type III and IV fractures require CT scan or MRI to assess extent of fracture and joint integrity. In general, the use of CT scans in the pediatric population is minimized due to the high levels of radiation exposure. Accessibility to high resolution MRI is making this test the imaging modality of choice for assessing osseous and non-osseous structures. These more complicated fractures often need surgical reduction and fixation to secure the fracture fragment. (Figures 6a and 6b) Long term follow up at six months and one year post injury is essential to monitor growth disturbances and arrest.

Patellar dislocations are relatively common in the female athlete. Mechanism of injury includes pivoting with femoral medial rotation on a planted foot. The athlete may report feeling or hearing a “pop” with concurrent knee buckling. The patella typically reduces spontaneously from its acute lateral position and rarely remains dislocated. A large joint effusion is noted on exam with pain on palpation at the medial femoral condyle and medial retinaculum. Lateral patellar apprehension test is positive. A hemoarthrosis can be indicative of medial retinaculum tears and/or an osteochondral fracture of the medial patellar facet or lateral femoral condyle. Imaging includes AP, lateral, and merchant view radiographs as well as MRI to assess cartilage injury and bone bruising. Conservative treatment consists of two to four weeks of knee immobilization followed by rehabilitation for quadriceps strengthening and improved patellar tracking. Recurrent patellar dislocation occurs in one in six episodes. Knee bracing is recommended for return to sport. Surgical fixation for patellar instability is only recommended after conservative methods of bracing and rehabilitation have failed. Acute surgical management is implicated for repair of large osteochondral fractures or excision of small fragments.
Lower leg
The ankle is the most commonly injured body part of athletes of all ages. In the youth athlete with an immature skeleton, the ankle is highly susceptible to physeal injury. An acute ankle physeal injury is frequently misdiagnosed as an ankle sprain. A growth plate fracture needs to be ruled out in this population by the mechanism of injury and objective findings. Pain on palpation is noted two centimeters (or about one finger width) above the distal fibula. Ankle ligaments may or may not be tender. Evaluation of bony tenderness at the base of the fifth metatarsal and fibular head is warranted for associated fractures. In young athletes with recurrent ankle injuries, tarsal coalition as a causative factor should be ruled out. Imaging for an acute ankle injury includes AP, lateral, mortise and comparison views. Salter Harris Type I fracture of the distal fibula is frequently unidentifiable on radiographs but will be treated as a fracture if the point of maximal tenderness is over the distal physis. The absence of swelling and ecchymosis is not an indicator of the absence of a fracture, i.e., a fracture may be present even if there is no significant edema or discoloration. Type I and Type II fractures heal rapidly once the fracture is identified and treated, generally with immobilization. Two to four weeks in a cast or walking boot is recommended with rest and protective weight bearing. Delayed diagnosis can lead to chronic pain, instability and increased time away from sports.

EMERGENCY CARE
Emergency care for acute traumatic injuries for the youth and adolescent athlete should follow American Red Cross guidelines for the emergency medical responder and generally does not differ greatly than management in an adult. What does differ is having to include the parents of the injured athlete, and have open lines of communication. A good rule of thumb for caring for the youth athlete is “when in doubt sit them out” keeping in mind the increased potential for possibility of a youth athlete sustaining an epiphyseal fracture as compared to a soft tissue injury. Refer to Figure 7 for specific guidelines. When managing upper extremity injuries, applying a sling or binder to the arm and securing to the body for transport is recommended. Guidelines on how to safely splint musculoskeletal injuries are listed in Figure 8. Frequent monitoring of neurovascular status post splint application is an absolute must to ensure proper circulation is being delivered to the distal tissues. Limb swelling post splinting can cause compartment syndrome.

CONCLUSION
The mechanisms of injury for acute traumatic disorders of the youth athlete are often similar to those of adult athletes, however, the injured structure is often very different. The young athlete with an immature skeleton has open growth plates and weaker bones which are prone to failure with excessive stress, therefore leading to more frequent fractures and cartilage injuries than muscular and ligamentous injuries that would occur in an adult. The majority of these fractures heal without sequelae when properly identified and managed early. Growth plate disturbances can potentially occur with all types of Salter Harris fractures. The youth athlete needs to be evaluated for a possible fracture prior to being given a diagnosis of a soft tissue injury.

Figure 7. Musculoskeletal injury care (from the American Red Cross).

- Ensure effective respiration
- Control bleeding if present
- Stabilize the head, neck and spine if spinal injury is suspected
- Maintain a comfortable, stable position of the injured area
- Remove any jewelry or clothing which may worsen the injury if swelling would occur
- Assess circulation and sensation
- Clean and bandage any open wounds before splinting
REFERENCES


ABSTRACT
Manuscripts have been subjected to the peer review process prior to publication for over 300 years. Currently, the peer review process is used by almost all scientific journals, and The International Journal of Sports Physical Therapy is no exception. Scholarly publication is the means by which new work is communicated and peer review is an important part of this process. Peer review is a vital part of the quality control mechanism that is used to determine what is published, and what is not. The purpose of this commentary is to provide a description of the peer review process, both generally, and as utilized by The International Journal of Sports Physical Therapy. It is the hope of the authors that this will assist those who submit scholarly works to understand the purpose of the peer review process, as well as to appreciate the length of time required for a manuscript to complete the process and move toward publication.

Key words: Peer review, quality control, research publication

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INTRODUCTION
Manuscripts have been subjected to the peer review process prior to publication for over 300 years. The Royal Societies of Edinburgh and London first began seeking help from their membership with the selection process of articles for their publication in the early to mid-18th century. Over time, other professional societies adopted the practice of peer review, however, as the process was introduced it was often disorganized and in most cases depended upon the chief editor. In the middle of the 20th century, the peer review process became more widespread and standardized. The main reason for the increased use of the peer review process is rooted in two main factors. The first of these is the proliferation of manuscripts. In the past, editors of new (and existing) journals often had to struggle to collect enough manuscripts to fill the pages of their journals and as such did not need to be selective. Subsequently, as the need for evidence-based practice has evolved, submissions to scientific journals have increased to the point where editors need to be much more selective in what gets published in their journals. The second reason for the increased use of the peer review process is the explosion of new information and technology. Areas of expertise have expanded to become more specialized and sophisticated. Because of this, editors were no longer able to be experts in all areas and had to seek opinions and advice from others. Currently, the peer review process is used by almost all scientific journals. The International Committee of Medical Journal Editors (ICMJE) defines peer review as: “[Peer review is] the critical assessment of manuscripts submitted to journals by experts who are not part of the editorial staff.” The purpose of this clinical commentary is to provide a description of the peer review process, both generally, and as utilized by The International Journal of Sports Physical Therapy (IJSPT). It is the hope of the authors that this will assist those who submit scholarly works to understand the purpose of the peer review process, as well as to appreciate the length of time required for a manuscript to complete the process and move toward publication.

WHAT SHOULD PEER REVIEW DO?
Scholarly publication is the means by which new work is communicated and peer review is an important part of this process. Peer review is an important part of the quality control mechanism that is used to determine what is published, and what is not. In the medical community, most scholarly work or research will not be seriously considered until it has been validated by peer review. Furthermore, the peer review process acts as a filter for interest and relevance to the field being targeted by a journal. Therefore, peer review should serve several purposes:

1. To help select quality articles for publication (filter out studies that have been poorly conceived, designed, and executed) with the selection being based upon:
   - The scientific merit and validity of the article and its methodology
     - Has the research that is being reported been carried out well with no flaws in the design or methodology?
     - Ensure that the work is reported correctly, with acknowledgement of the existing body of work.
     - Ensure that the results presented have been interpreted correctly and all possible interpretations considered.
     - Ensure that the results are not too preliminary or speculative, but at the same time not block the sharing of innovative new research and theories.
   - The relevance of the article to the specific clinical practice – select work that will be the greatest interest to the readership
   - The interest of the topic to the clinical reader
   - The presentation and understandability of the article itself

2. To improve the manuscript whenever possible.
   - Generally improve the quality and readability of a publication.

3. To check against malfeasance within the scientific and clinical community.

4. Provide editors with evidence to make judgments as to whether articles meet the selection criteria for their particular publication.
The main functions of the peer review process are to help maintain standards and ensure that the reporting of research work is as truthful and accurate as possible. Peer review contributes to the ongoing process used by individual clinicians to assess what information to believe and what to view with skepticism. This occurs because individual clinicians with varied levels of experience know that a peer reviewed, published manuscript has been reviewed and deemed worthy by others, often with greater or more varied experience than they possess. While most clinicians have the ability to critically read a research manuscript, they cannot be expected to be experts in all areas and make judgments about topics about which they know little.5

THE PEER REVIEW PROCESS

The peer review process is similar for all journals, with some variation expected between journals. The procedure described here is the process used by IJSPT with manuscript submissions. Once an author submits a manuscript through the online submission process, it is automatically logged in and checked to make sure that the submission is complete and has been prepared according to the IJSPT submission instructions. At this time a receipt of manuscript acknowledgement is sent to the author to let them know that their manuscript has been received. Each manuscript is then read by an editor (either individually or in consultation) to assess its suitability for the journal according to the guidelines determined by the editorial policy. This is an important step to ensure that (1) the content falls within the scope of the journal, (2) the manuscript follows editorial policy and procedural guidelines, and (3) that it does not contain an unacceptable level of overlap with manuscripts that are already in press. A manuscript could be rejected without additional review for one or more of the previous reasons, and the author notified.

While manuscripts can be rejected without involving additional reviewers, they cannot be accepted for publication without additional review. So if a manuscript is not rejected when first received, it is then sent out for review to a minimum of two additional reviewers who are part of the journal’s cadre of reviewers. Review by Associate Editors or staff may compliment this process. Within the medical and scientific communities, debate continues as to the precise form that a peer review should take. The closed review process is the traditional form of peer review adopted by most journals. One prominent area of contention is the subject of blinding. The most common model seems to be the single-blinded review, in which the reviewer’s identities are withheld from the authors but the reviewers are aware who wrote the paper they are evaluating.6 This system has been heavily criticized for having the potential for bias because work originating from certain authors, institutions, or geographic regions may be treated more or less critically. The second type of blinding is the double-blind review. With a double-blind review the identity of the authors is also masked during the review process. Both the authors and the reviewers are unaware of each other’s identity. This type of review has been popularly endorsed in author surveys and is the model employed by the IJSPT.6 While the double-blind process does appear to be a much fairer method of assessment as compared to the single blind review, this peer review process does have some limitations. Manuscripts that draw heavily on the submitting authors previous research may be difficult to mask effectively while still giving the reviewers the information they need to evaluate the study thoroughly.6,7,8 Since the reviewers are often content experts within a given topic area, they may get enough clues from the citations in the manuscript and/or from their knowledge of the work going on in that topic area to hypothesize as to whom the author may be. Therefore, although it has been suggested that blinding reviewers to author identity leads to better opinions and reviews, this assertion has not been proven in trials.9,10 Much can be done to help with this problem through careful attention to the manner in which earlier work is referenced in a paper, although some authors may intentionally make their identity easier to discern if they feel their reputation (and citing their previous publications liberally) will garner better treatment from the reviewers.

Once reviewers are chosen and they accept their review assignment, the real process begins. Most reviewers use some form of checklist that covers some or all of the considerations offered in Appendix 1. Note that this checklist is best utilized with papers that are submitted in the category of Original Research, and different criteria or salient points for assessment may be utilized for other types of submissions such as Case Reports, Clinical Commentaries, and Clinical Suggestions.
The reviewers return their recommendations and reports to the editor (via the online submission system), who assesses them collectively, and then makes a decision, either on his or her own or in consultation with other editors on whether to reject the manuscript (either outright or with encouragement to resubmit), to withhold judgment pending major or minor revisions, to accept it pending satisfactorily completed revisions, or to accept it as written. Rarely, if ever, is a manuscript accepted as written! For manuscripts accepted pending revision, the authors must submit a revised manuscript that will go through all or some of the stages above. Once a manuscript has been revised satisfactorily (more than one revision may or may not be allowed) it will be accepted and put into the production process to be prepared for publication. An outline of this process can be seen in Figure 1. Despite the apparent simplicity in this process, the actual steps may be quite elaborate and involve a number of people and alternative procedures, thus requiring substantial time to complete.

Figure 1. A graphic display of the “path” a manuscript takes after submission to The International Journal of Sports Physical Therapy.
CONCLUSION
While the peer review process is unlikely to change the basic nature of a given submission, in many cases the authors may add analysis or results, clarify thoughts or parameters, revise the statistical testing methods, increase the number of subjects, or lengthen the time of clinical follow-up in response to reviewer’s requests. Most typically, thoughtful comments provided by reviewers lead to improvements in the presentation of the work in several ways: clarity in writing and descriptions are enhanced, relevant literature is discussed more thoroughly, limitations of methodology are acknowledged, and broad or overreaching conclusions are moderated. This can only happen when knowledgeable reviewers take time to participate in the peer review process and evaluate submissions with care and sensitivity. The editors and reviewers of IJSPT are committed to utilization of a stringent yet fair review process in order to assist those who submit scholarly work for publication.

REFERENCES:
APPENDIX 1: SAMPLE REVIEW GUIDELINES

Title: Does it accurately reflect the purpose, design, results, and conclusions of the study?

Abstract: Does it correctly and succinctly summarize the salient points of the study?

Introduction: Does it provide adequate background and rationale for performing the study?
  o Does it place the study in the perspective of research conducted previously in the field?
    • Why is study being done? Identify controversy?
  o Is the literature discussed in the introduction adequate to introduce the purpose of the manuscript?
    • Is the functional, biological, and/or clinical significant of the topic established.
    • Strengths and limitations described such that a need for further study is established.
  o Is the literature discussed in the introduction directly related to the purpose of the manuscript and necessary to introduce the topic?
  o Is it clear how the experimental approach to be used in the present study is likely to yield more definitive or unique insight than previous studies?
  o Does it clearly state or imply the study hypothesis(es) or null hypothesis?
  o Are the outcomes to be measured clearly described in the introduction or methods section?
  o Does the introduction adequately introduce the purpose of the manuscript in a logically compelling way?
  o Is a clear and strong rationale provided for the importance of this manuscript?

Study design and methodology: Is the sample described in appropriate detail; procedures and data analysis described clearly and in sufficient detail?
  o IRB approved?
  o Type of study described? (RCT, Cohort, Case controlled, Case report, etc)
  o Is the experimental design of the study capable of answering the question implied by the study hypothesis?
    • Do the methods address the purpose?
  o Is there a control or comparison group in the treatment study?
    • Are there factors not controlled between the groups: (list)
  o Is the study: Prospective or Retrospective
  o Is the methodology described in sufficient detail for others to repeat study
    • Is it reproducible?
    • If not, do the authors provide a proper (peer reviewed) reference that would provide such details?
  o Is there a rationale for the experimental design?
  o Is the Study Population clearly identified
    • Identified and appropriate to answer question?
    • Informed consent obtained?
    • Admission criteria clearly specified?
      • Inclusion / exclusion criteria
    • Power analysis provided?
      • Where enough subjects studied to detect a difference?
    • Were subjects randomized?
      • What methods were used?
      • If subjects were not randomized, were subjects and controls equivalent?
      • Was the randomization assignment concealed from both patients and healthcare staff until recruitment was complete and irrevocable?
    • Will the subject population allow extensive or rather limited generalizability?
External validity:
- Were the subjects asked to participate in the study representative of the entire population from which they were recruited?
- Were those subjects who were prepared to participate representative of the entire population from which they were recruited?
- Were the staff, places, and facilities where the patients were treated representative of the treatment the majority of patients received?

Internal validity:
- Was an attempt to blind study subjects to the intervention they have received?
- Was there an attempt made to blind those measuring the main outcomes of the intervention?
  - Blinding
    - Single-blind (patient)
    - Double-blind (patient & investigator)
- If any of the results of the study were biased on the data dredging, was this made clear?
  - Any analysis that had not been planned at the outset of the study should be clearly indicated.

Therapeutic intervention clearly defined? Treatments should be clearly described.

Measurement Instrument or method clearly described?
- Standard accepted measurement instrument or method? (ie. Universal?)
- Are metrics provided for standard instruments, procedures, or methods?
- Non-standard
  - Unbiased?
  - Validated?
  - Reproducible?

Are the details as to how the data were derived (calculated) adequately explained so that they can be confirmed by the reviewer and reproduced by future investigators?

Is it clear how the data will be interpreted to either support or refute the hypothesis?

Have the characteristics of patients lost to follow-up been described. Follow-up
  - Adequate length?
    - Minimal____ Average____
  - Is mechanism of follow-up described?
  - Loss to follow-up reported?

Soundness of the Results: the outcome of the statistical analysis are presented appropriately and interpreted accurately.

Are the data reported in a clear, concise, and well-organized manner?
- Is there excessive variability in one or more of the measurements for a particular condition compared with others?

Are the main findings of the study clearly described? Simple outcome data should be reported for all major findings so that the reader can check the major analyses and conclusions.

All results must be proposed in the methods.
- Are they relevant to the study or research problem?
- Are data presented that was not described in the methods?

Reported in sufficient detail?
- Statistical results tell statistical significance?
- Actual results tell clinical significance?
Was compliance with the intervention reliable?

Do the tables and figures clarify or confuse?
  - Are all the figures and tables needed?
  - Are the tables and figures properly labeled with titles and the correct units?
  - Is the scaling of the figures appropriate and unbiased?

Was randomization successful?

Statistics:
  - Appropriate test(s) chosen?
  - Appropriate p-value chosen (a priori)?
    - Have the actual probability values been reported rather than <0.05 for the main outcomes except were the probability value is less than 0.001.
    - Have adjustments been made for multiple comparisons?

Does the study provide estimates of the random variability in the data for the main outcomes?

Does the analysis adjust for different lengths of follow-up of patients, or in case-controlled studies, is the time period between the intervention and outcome the same for cases and controls?

If findings are negative, was a sufficiently large population studied?
  - Remember: failure to show a difference is NOT the same as showing that there is no difference – may be a lack of power.

Have all the important adverse events that may be a consequence of the intervention been reported?

Are findings clinically significant?
  - How do the group differences or responses shown compare with the measurement variability?

**Discussion and Conclusion:** The implications of the study are consistent with the purpose, methods, and data analysis.

**Discussion**

- Are the major new findings of the study clearly described and properly emphasized?
  - Is the significance of the present results described?
  - Is it clear how the findings extend previous knowledge in a meaningful way?

- Does it point out weaknesses/limitations of the study?

**Biases:**
  - Selection
  - Performance
  - Detection (measurement)
  - Transfer (loss of follow-up)

- Does it point out the strengths of the study?

- Does it place the study in perspective with existing literature?
  - Discuss similarities and differences
  - Are important experimental observations from previous reports described in the context of the present results?

- Excessive speculation?
  - Does it distinguish author opinion from the conclusions
  - Do the authors support their statements with appropriate references?
  - Do the authors discuss their data in a manner that provides insight beyond that presented in previous sections?

- Is there any other way to interpret and/or explain the data other than that suggested by the authors?

**Conclusion**

- Was hypothesis proved?
• Is it based on the data described in the results?
• Key conclusions adequately supported by the experimental data?
  o Does it point out the clinical significance of the conclusions?
  o Does it suggest the possible direction of future investigation?
    • Do authors make suggestions as to how the results of their study need to be extended in the future to learn more about the issue in question?
  o Are conclusions justified by the results of the study?
    • Does it stray beyond the boundaries of the study?

**Organization and Style**

  o Is the manuscript concise?
    • Is the material presented, without excessive jargon?
    • Are all the graphs or charts needed?
  o Was the paper well written, properly organized, and easy to follow?
  o Was proper grammar, spelling, and punctuation used throughout?
  o Should manuscript be shortened?
  o Should manuscript be more comprehensive?

**References**

  • Are the major references included?
  • Are all references cited completely and in the desired format of the journal
  • References chosen directly relate to the study?
  • Avoids secondhand or abstract reference sources?
  • Are all references cited correctly in text, e.g. superscripted following punctuation.

**Overall Significance and Suitability**

  o Is the manuscript sophisticated enough for the intended professional audience?
    • Was the information presented in an open-minded and objective manner?
  o Is the experimental question significant?
  o Is a clear and testable hypothesis presented?
    • Overall method is valid?
  o Results are properly presented and believable?
  o Conclusions are reasonable on the basis of the results obtained?
  o Does manuscript contain new findings or ideas?
  o Does the manuscript provide a unique contribution?
    • If not, does it present old material better?
ABSTRACT

A push for the use of evidence-based medicine and evidence-based practice patterns has permeated most health care disciplines. The use of evidence-based practice in sports physical therapy may improve health care quality, reduce medical errors, help balance known benefits and risks, challenge views based on beliefs rather than evidence, and help to integrate patient preferences into decision-making. In this era of health care utilization sports physical therapists are expected to integrate clinical experience with conscientious, explicit, and judicious use of research evidence in order to make clearly informed decisions in order to help maximize and optimize patient well-being. One of the more common reasons for not using evidence in clinical practice is the perceived lack of skills and knowledge when searching for or appraising research. This clinical commentary was developed to educate the readership on what constitutes evidence-based practice, and strategies used to seek evidence in the daily clinical practice of sports physical therapy.

Key words: Evidence-Based Medicine, Sports Physical Therapy, Rehabilitation

INVITED COMMENTARY

EVIDENCE – BASED MEDICINE/PRACTICE IN SPORTS PHYSICAL THERAPY

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INTRODUCTION

The American Physical Therapy Association 2020 Vision Statement suggests that physical therapists and physical therapist assistants will render evidence-based services throughout the continuum of care and improve quality of life for our society. This statement is in sharp contrast to what actually occurs in typical practice. According to Shuster and colleagues, 30-40% of patients do not receive care according to current scientific evidence and about 20-25% of care provided is not needed or is potentially harmful.1 A study of 321 physical therapists in England and Australia found that the basis for over 90% of each group's choice of treatment interventions reflected what was taught during their initial training despite more recent research and outcomes findings presented in the medical literature.2 Actually, research literature was ranked as least important as a basis for choosing treatment interventions and techniques, and ideas gleaned from review articles ranked higher. Jette and colleagues report that although most agree that evidence-based practice (EBP) is important, far less make time to practice it due mainly to lack of time and lack of skills necessary to implement its use.3 Another serious problem faced by physical therapists is that rehabilitation journals may publish research articles with lower methodological quality, as described by Miller, McKibbon and Haynes who found that only 19 of 179 journal articles published in four different physical therapy journals met standards of rigor as defined by the Hedges Project Criteria.4 Adding salt to our physical therapy wounds is the fact that many of these research articles do not even study clinical populations.5 Fortunately for physical therapists, this appears to be a more universal problem, and other professions such as orthopedic surgery and other medical specialties suffer from the same. The percentage of Level I studies published in the prestigious Journal of Bone and Joint Surgery has slowly increased from 4% to 21% between the years of 1975 and 2005.6 It is the hope of the authors that this manuscript will dispel some of the fears associated with using Evidence-based medicine (EBM) in your day-to-day practice of sports physical therapy. Finding the evidence needed to guide and inform clinical practice is getting easier than ever before! The goal of this commentary is that the readership of IJSPT will have the necessary tools to practice using EBP. This commentary is designed to present key skills and tips in order to practice EBM in a clinical setting.

What is Evidence-Based Medicine (EBM)/Practice (EBP)

EBM was developed due to a clear need to optimize quality of patient care. EBM has been touted as an effective series of mechanisms not only for improving health care quality, but also for reducing medical errors precipitated in part by clinical practice variation. In present day medical practices, clinicians are expected to integrate clinical experience with conscientious, explicit and judicious use of research evidence in order to make clearly informed decisions to help maximize and optimize patient well-being. Although EBM has been a buzzword for some time now, many sports physical therapists are still not completely sure of how to integrate EBM into daily clinical practice and how to use it as a part of their continued professional growth. EBP is an approach to health care in which sports physical therapists use the best available evidence to make clinical decisions for individual patients during daily clinical practice. This article is the first of this special collection presented in the International Journal of Sports Physical Therapy (IJSPT) – A User Friendly Guide to Publishing in the International Journal of Sports Physical Therapy. This commentary will serve as an overview while others that follow will describe details about authorship and publishing in IJSPT.

Interest in EBM surged following the coining of the term published in JAMA in 1992.7 Sackett et al described EBM as “integration of the best research evidence with clinical expertise and patient values and circumstances to make clinical decisions.”8, p. 71

What does this mean to us as sports physical therapists? Best research evidence means clinically relevant research sometimes from basic sciences of medicine, but especially from patient-centered clinical research into the accuracy and precision of diagnostic tests (including the clinical examination), the power of prognostic markers, and the efficacy and safety of therapeutic, rehabilitation, and preventive strategies. The most updated clinical research does more than simply suggest new ways to diagnose pathology and approach treatments. It can often
invalidate older ways of diagnosis and methods of treatment and replace them with more powerful, valid, or successful methods. Clinical expertise means the ability to use clinical skills and past experience to rapidly identify each athlete’s unique health state and diagnosis, their individual risks and benefits associated with potential interventions, while skillfully integrating their personal values and expectations. Clinical expertise, personal to each physical therapist, is developed over time and requires exposure to variety in patient care, and ultimately is very hard to replace. It is clinical expertise that allows each physical therapist to apply new evidence from peer-reviewed journals, symposia, and meetings. Each athlete is a unique individual with their own concerns, experiences, priorities and preferences. Patient values means the unique preferences, concerns and expectations each athletic patient brings to a clinical encounter. These must be integrated into clinical decisions if they are to serve the athlete. A relevant clinical decision must integrate the athlete's unique considerations into the decision-making process. Patient circumstances means the athletic patient's individual clinical state and clinical setting.

Although this concept is not entirely new it has seen resurgence since the early 1990's. In sports physical therapy, EBM should be based upon patient-centered, clinically relevant research found in literature related to diagnostic tests, intervention techniques, preventive programs, and prognostic markers of sports related injuries. As a reader of the International Journal of Sports Physical Therapy, you already realize that this is a daunting task, as new evidence is continuously emerging. Evidence at any time can affect the use of or change thinking regarding commonly used and accepted methods of examination or treatment of musculoskeletal conditions. Therefore, what constitutes an acceptable method of treatment may change at any time. Reviewing and assimilating the abundance of evidence can be a daunting task as the volume of published literature continues to rise. There has been an explosion in the number of randomized controlled trials in physical therapy over the last 80 years. In 1929 there was only one randomized controlled trial related to physical therapy interventions published. This has jumped to roughly 12,000 randomized controlled trials in 2009. In a study of family physicians it was determined that clinical questions about patients care arose 3.2 times for every 10 patients seen, yet physicians did not seek an answer 64% of the time. According to Ely, most clinical questions don't get answered and most of the times that is because the physician does not want or have time to pursue the answer. The most common reason for not pursuing an answer was that after voicing some uncertainty, the doctor felt that a reasonable decision could be based on his or her current knowledge.

How to Use EBM in Sports Physical Therapy Practice

Sackett et al and others have proposed several steps that will be discussed in greater detail throughout this manuscript.

1) Convert the need for information (about prevention, diagnosis, prognosis, therapy, causation, etc.) into an answerable, clinically relevant question.
2) Track down and search for best evidence with which to answer the question.
3) Critically appraise the evidence for its validity (closeness to the truth), impact (size of the effect), and applicability (usefulness in our clinical practice).
4) Integrate the critical appraisal with clinical expertise and with your patient's unique biology, values and circumstances.
5) Evaluate effectiveness and efficiency in executing steps 1-4 and seeking ways to improve upon them before next time.

Straus and colleagues have found that real world clinical incorporation of these steps is done in several fashions. In many instances the first four steps are done by clinicians, while the final step of evaluation of effectiveness is left out. Another common method is to skip steps 1-3 and use a source of information that has already undergone review by another clinician. An example of this might be integrating findings from a systematic review or meta-analysis, or evidence summaries that have been written or presented by others, without personal review. A final method is to follow recommendations of respected leaders in sports physical therapy. In reality most cli-
nicians probably use all three of these methods of practicing EBM at one time or another depending on the condition that they are using it for. In select sports physical therapy encounters, going through all steps listed above is probably very prudent as you want to be as up to date as possible. An example might be the clinical usefulness of joint mobilization on a postoperative knee or shoulder that has become stiff. However, for a condition that is rarely seen such as acute rhabomyolysis the sports therapist may accept the recommendations that are received from other experts more experienced with this condition.

Defining a Clinical Question
Evidence-based clinical questions should start and end with the athletic patient in mind. Clinical situations arise daily in the sports physical therapy clinic which requires asking a clinical question about which course of action is best. If the athlete has an unusual pathology or a condition that is rarely seen, the clinician may be uncertain of appropriate care. Without a doubt, in this case, there is a need for relevant information related to diagnosis, prognosis, or management of the condition(s). This may mean that evidence must be searched for. There may not always be an easily found protocol such as those for SLAP tears or anterior cruciate ligament reconstructions. For example, the therapist may suspect a deep venous thrombosis which may be a life threatening situation, or an athlete presents following a medial patellofemoral ligament reconstruction which is a novel procedure for the therapist. In these instances the therapist may not have an easy protocol “cookbook” to follow and will come to a point in the clinical decision-making process where answerable questions need to be formulated. Questions that need to be asked may pertain to one or more of the following and evolve around care of the patient (Table 1).10

Clinically based questions can come in two general forms: background or foreground questions. A background question is needed to understand the nature of

<table>
<thead>
<tr>
<th>Table 1. Central Issues in Clinical Work, Where Clinical Questions Arise.</th>
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<tr>
<td>1. <strong>Clinical Findings</strong>: how to properly gather and interpret findings from the history and physical examination.</td>
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<tr>
<td>2. <strong>Etiology/Risk</strong>: how to identify causes or risk factors for disease (including iatrogenic harms).</td>
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<tr>
<td>3. <strong>Clinical Manifestations of Disease</strong>: knowing how often and when a disease causes its clinical manifestations and how to use this knowledge in classifying our patient’s illnesses.</td>
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<td>4. <strong>Differential Diagnosis</strong>: when considering the possible causes of our patients’ clinical problems, how to select those that are likely, serious, and responsive to treatment.</td>
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<td>5. <strong>Diagnostic Tests</strong>: how to select and interpret diagnostic tests, in order to confirm or exclude a diagnosis, based on considering their precision, accuracy, acceptability, safety, expense, etc.</td>
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<tr>
<td>6. <strong>Prognosis</strong>: how to estimate our patients’ interventions (?) that do more good than harm and that are worth the efforts and costs of using them.</td>
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<tr>
<td>7. <strong>Prevention</strong>: how to reduce the chance of disease by identifying and modifying risk factors and how to diagnose disease early by screening.</td>
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<tr>
<td>8. <strong>Experience and Meaning</strong>: how to empathize with our patients’ situations, appreciate the meaning they find in the experience, and understand how this meaning influences their healing.</td>
</tr>
<tr>
<td>9. <strong>Improvement</strong>: how to keep up-to-date, improve our clinical and other skills, and run a better, more efficient clinical care system.</td>
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an athlete’s problem, a test, or a treatment. The essential components of a good background question are 1) a question root (who, what, where, when, how and why), and a verb. 2) A disorder, test, treatment, or other aspect of care. An example of several background questions relevant to sports physical therapy include:

- How long does it take scar tissue to create limited motion in the knee following surgery?
- What are common signs and symptoms of a superior labral tear?
- What are the causes of shoulder internal impingement in an overhead athlete?
- Is it possible to return to unrestricted pitching following ulnar collateral ligament reconstruction of the elbow?

A foreground question helps the clinician and athlete to make decisions about the specific management of their athletic condition or injury, and/or management of that problem. These questions are a little larger and have 4 essential components that can use the PICO format. The PICO acronym is described below, followed by several foreground questions that may be asked by a sports physical therapist.

1) P: Patient, population, predicament, or problem. Information involves demographics such as age, sex and race. Other important information could include social situations, resources and patient values, and the clinical setting.

2) I: Intervention, exposure, test, or other agent. What type of intervention is being considered? Is this a medication of some type or a form of diagnostic imaging such as radiograph or ultrasound imaging? Or is the intervention at this point a given special test the sports therapist is using to determine the pathology?

3) C: Comparison, intervention, exposure, test, etc., if relevant. The treatment itself can only be compared with something else other than itself. The comparison may be with another medication, another form of imaging such as magnetic resonance imaging, to a current standardized treatment or to no treatment at all.

4) O: Outcomes of clinical importance, including time when relevant. What would be the desired effect you would like to see? What effects are not wanted? Are there any side effects involved with this form of testing or treatment?

- In adolescents following anterior cruciate ligament reconstruction, would the addition of neuromuscular electrical stimulation early in therapy result in better return of quadriceps motor control and, therefore, better graft stability?

- Will the initiation of early passive range of motion result in improved subjective outcome scores compared to delayed range of motion for college-aged pitchers with small undersurface rotator cuff tears?

As a sports physical therapist the amount of time that is spent using the two different types of questions will vary with your experience. Early in your career when you have limited clinical experience you may utilize an overabundance of background questions simply to better understand a given pathology. As you become more seasoned and have a general knowledge of most conditions you are more likely to ask foreground types of questions. This is by no means meant to imply that the seasoned clinician will not need to ever ask a background question or that a more novice clinician may not need to ask a foreground question. Each of these types of questions can be used by either clinician regardless of their level of experience.

Once a patient-centered clinical question has been devised, it is important to plan a strategy for a search before jumping into the wide variety of sources of evidence that are available. The next section of this manuscript therefore will describe how to search for the best available evidence.

**How to Search for Best Available Evidence**

Searching for the best available evidence can be a daunting task without knowledge of efficient search strategies. As mentioned previously, the number of randomized controlled trials has grown exponentially, so much that a physical therapist who graduated in 1980 now has access to 25 times more randomized controlled trials about physical therapy treatment than they graduated. Moreover, finding an article that meets basic criteria for quality and relevance among the throngs of available journals may be like looking for a needle in a haystack.
McKibbon et al stated that the number of articles a clinician would need to read to find just one article that meets such basic criteria among the largest four general/family practice journals is between 107 and 226 articles.14

At the risk of sounding like the imperial authorities in Ray Bradbury’s Fahrenheit 451, the harvesting of the best available evidence should begin by burning (or at least dismissing) all textbooks with the exception of the best of a new breed of them. In most texts, it’s not possible to tell which information is current or supported by anything more than anecdotal evidence. Therefore, while some useful information about background questions may be found in texts, most are significantly suboptimal when attempting to find the best evidence-based answers for clinical foreground questions.15 For example, textbooks may be able to accurately articulate that patients with patellofemoral pain syndrome often display reduced lower extremity muscle function; however, a 2011 study concerning patellofemoral pain syndrome is able to provide concrete evidence that a group of females with the condition generated 22% less hip abductor and 21% less hip external rotator force output on a hand-held dynamometer than controls.16

Multiple online databases exist from which clinicians can search for evidence to support their practice. PubMed (http://www.ncbi.nlm.nih.gov/pubmed/), EBSCO (http://www.ebsco.com/), Ovid (http://www.ovid.com/), and Google Scholar (http://scholar.google.com/) are among the most popular. For the purpose of brevity, this manuscript will describe searching from PubMed. Moreover, the listed databases all have comprehensive “Help” tabs that explain how to search the respective databases in depth; therefore, the information here will focus on describing components of efficient searches for clinical research, assuming a reader with basic knowledge of online searching.

After developing a PICO question as described in the previous section, it is important to select the best words or phrases to use as search terms. Given the aforementioned PICO question, “In adolescents following anterior cruciate ligament reconstruction, would the addition of neuromuscular electrical stimulation early in therapy result in better return of quadriceps motor control and, therefore, better graft stability?”, the phrases “anterior cruciate ligament reconstruction” and “neuromuscular electrical stimulation” are essential to the query. The next step is to determine which words or phrases are most recognizable by the database. MeSH (Medical Subject Headings) is the vocabulary thesaurus used for indexing articles to PubMed (Figure 1) (http://www.ncbi.nlm.nih.gov/mesh). For example, the terms “ACL” and “neuromuscular electrical stimulation” are not recognized by the database and their use, therefore, would result in suboptimal search outcomes. “Anterior cruciate ligament” and “electric stimulation,” however, are recognized subject headings relevant to this example. Terms discovered within the MeSH data-
base can be selected and automatically included in a search builder from which PubMed searches can be performed with the option of selecting the AND, OR, or NOT Boolean operators (Figure 2). The Boolean search operators define relationships between search terms and assist with providing more focused results than single search words or terms.

Another excellent launch pad for a search with relevant words or phrases is PubMed’s Clinical Queries tool (Figure 3). Searches within Clinical Queries are able to limit results to specific clinical research areas. For example, search results can be filtered through the categories of Etiology, Diagnosis, Therapy, Prognosis, and Clinical prediction guides using a drop-down bar. Moreover, each Clinical Queries search can be further filtered with a Broad or Narrow scope with another dropdown bar (Figure 4). Narrow searches deliver clinical trials, randomized controlled trials, and systematic reviews. Broad searches deliver similar research with the inclusion of other review articles. The use of these filters results in a significantly more focused delivery of evidence than using the same terms to search from the PubMed home page. For example, searching “anterior cruciate ligament AND electric stimulation” from PubMed’s home page delivered 67 results in September of 2012; whereas the same search using a Narrow scope filter in the Therapy category of Clinical Queries resulted in 23 relatively higher quality evidence more specific to therapeutic intervention.

Critically Appraising Evidence
Once evidence relevant to one’s clinically-oriented question is found, it must be critically appraised to determine its value and subsequent benefit to clinicians and patients. The Centre for Evidence Based Medicine describes a hierarchy of evidence with the use of numerical levels and letter grades to define the quality of each piece of clinical evidence (http://www.cebm.net/index.aspx?o=1025). Higher levels of study designs allow clinicians to have increased

Figure 2. The textbox of the PubMed search builder within its MeSH database is shown. The dropdown box in the lower right hand corner can be used to select the AND, OR, or NOT Boolean operators.

Figure 3. The location of the Clinical Queries link on PubMed’s home page is indicated by the addition of the highlighted yellow rectangle. Searches within Clinical Queries are able to limit results to specific clinical research areas.
confidence in the conclusions drawn within the study. Levels described in the Therapy column of the Centre for Evidence Based Medicine’s hierarchy are as follows (listed from best evidence to that in which clinicians can place least confidence): systematic reviews (SR) of randomized controlled trials (Level 1a); individual randomized controlled trial (1b); SR of cohort studies (2a); individual cohort studies (2b); SR of case-control studies (3a); individual case control study (3b); case-series (4); and expert opinion without explicit clinical appraisal, or based on physiology (5). These levels of evidence can sometimes be found within the online abstracts of articles, and they are now being noted in most respected journals, such as the International Journal of Sports Physical Therapy, within their respective articles. One efficient method for further determining the quality of clinical trial evidence is by using the PEDro score (http://www.pedro.org.au/english/downloads/pedro-scale/) and/or the corresponding PEDro website database. PEDro is the Physiotherapy Evidence Database, a free database of over 22,000 trials, reviews, and guidelines with links to citation abstracts and full texts where possible (http://www.pedro.org.au/). The PEDro database rates evidence with a score out of ten based on the following validity criteria of a research study: eligibility criteria specified; subjects randomly allocated to groups; allocation was concealed; homogeneity of groups; blinding of all subjects; blinding of all therapists administering treatment; blinding of all assessors who measured an outcome; measures of at least one outcome were obtained from more than 85% of the sample; all subjects received the treatment or control condition, otherwise there was an “intention to treat” analysis; the results of between-group statistical comparisons are reported; and the study provides point and variability measures for at least one outcome (http://www.pedro.org.au/english/downloads/pedro-scale/). Search results within PEDro will display relevant systematic reviews; however, scoring with the above criteria is not applicable to such reviews as it is to clinical trials (Figure 5). In the event that evidence is not yet appraised within PEDro, the presence of the aforementioned validity criteria can be determined by searching the full text of an article or turning to the American Physical Therapy Association’s (APTA) growing database called “Hooked on Evidence” (http://www.hookedonevidence.com/). Hooked on Evidence aids in critically appraising evidence by dissecting study

Figure 4. Dropdown bars displaying the category and scope filters within PubMed's Clinical Queries tool are shown. Narrow searches deliver clinical trials, randomized controlled trials, and systematic reviews. Broad searches deliver similar research with the inclusion of other review articles.
specifics and presenting them in an organized fashion. In addition to the majority of validity criteria rated by PEDro, Hooked on Evidence provides additional description of an article’s study population and intervention specifics, as well as visual representations of study data. Moreover, if a study has been rated using the PEDro score, Hooked on Evidence provides a link to the scoring above the citation's title (Figure 6).

An article's level within the research hierarchy, study purposes, compositions of participants, and measures of methodological quality are all important components to consider when critically appraising evidence. The use of PEDro scoring and APTA's Hooked on Evidence is extremely helpful for determining such components. It is only after critically appraising the research that a clinician can judge the amount of confidence he or she can have in the application of such evidence to clinical practice.

### Integration and Application of Evidence with Sport Physical Therapy

Now that you have found information that you have determined to be valuable; meaning you have determined it was reliable, valid, clinically important information related to your given clinically-oriented question, it is time to integrate this newly found information into the particular situation involving your athlete. This implies making decisions about how to apply the findings to treat the athlete sitting in front of us! The ability to fully integrate this best evidence with clinical experience into practice is twofold: (1) one must be comfortable and capable with integrating EBM into his or her practice, and (2) one must be able to understand and incorporate the

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**Figure 5.** Search results are shown for ‘anterior cruciate ligament AND electric stimulation’ within PEDro. PEDro scoring is not as applicable to systematic reviews as it is to clinical trials; nonetheless, they are listed first.
patient's needs and wants to establish the best course to follow in terms of treatment and management.9

Remember that just because you have found information to be important does not mean it must be included in how you examine, evaluate, or treat your given patient. The information gained may not be right for your given case, patient, or client. As described in this article EBM should always be patient centered and in some instances information gained may not be able to be utilized. For example your search may indicate that in most patients with a given inflammatory condition treatment with xx brand of steroidal medication may be best in conjunction with physical rehabilitation. If you patient has an extreme allergy to that medication, despite high level evidence indicating efficacy with its use – this option is not going to work for you as it is contraindicated with this patient. What if in this same instance your patient has limited insurance and it does not cover the cost of the medication? The evidence that was discovered would not be applied in this instance, due to cost. The extreme importance of an athlete's perspectives, beliefs, expectations and goals cannot be given short thrift. By
considering how your athlete thinks about the available options and their relative risks, benefits, harms, costs, and inconveniences when determining options through evidence and clinical expertise, the astute therapist engages in a shared decision making process. In these scenarios where the evidence points to treatments that are not viable for various reasons the sports physical therapist will have to draw on past experiences and use other methods of treatment for the patient in this scenario to improve. Using EBM the clinician must factor in patient preferences, cost, and convenience. By listening to your athletic patient to understand his or her personal situations and goals and working with your informed athlete to achieve a common ground on a treatment approach, you, as the sports physical therapist can deliver effective patient-centered care.

Make sure to use valuable resources to obtain your information not only opinion based guidelines that are not backed by science. These opinion based guidelines have been referred to as “BOGSAT’s” because they were developed by a Bunch of Old Guys Sitting Around Talking. There are several resources that have been developed to help busy sports physical therapists to identify and integrate the best available research evidence with their clinical expertise. Clinical guidelines have been developed based on best available evidence and provide a good starting point for commonly encountered clinical scenarios. For example, the Journal of Orthopedic and Sports Physical Therapy has published clinical guidelines on heel pain – plantar fasciitis. Additionally, the American Physical Therapy Association (APTA) has developed PT Now which is a tool for APTA members to gain access to clinical practice guidelines relevant to physical therapist practice. PT Now is presently in early stages of development but has been working closely with the Sports Physical Therapy Section on development of practice guidelines that will be helpful for sports physical therapists. The PT Now website link is: http://www.ptnow.org/EBPLibrary/PracticeGuidelines.aspx

Another very important aspect of integration of evidence into practice is to share your findings with others. Teach other sports physical therapists what you have found with your searches. Allow others to learn what you have found. This can be done at a regularly scheduled meetings or in a more formal “journal club” type of format in which findings are passed out prior to the meeting so that members can review evidence beforehand in hopes that better discussions will be brought forward in valuable meeting time. Another way to help integrate evidence into practice is through attendance of continuing education meetings and workshops that are evidence-based. Evidence does exist that demonstrates educational meetings alone or combined with other interventions, can improve professional practice and healthcare outcome for patients.

Evaluating Performance of EBM

The integration and application of evidence with sports physical therapy is paramount considering a study done by McCluskey and Lovarini. These authors studied the extent to which practice behavior changed as a response to an evidence-based education intervention. They concluded that EBP skills and knowledge improved markedly; however, changes in behavior were small. Such results emphasize the importance of establishing new routines and priorities around EBP, as well as the need to continually evaluate the performance of the EBP approach. Behavior change may take months or even years, but it’s imperative in order to provide the best care to athletes.

Evaluation of performance in practicing EBM is essentially the process of answering questions such as the following:

1. Am I asking any well-formulated questions?
2. Am I becoming more efficient in my searching?
3. Am I critically appraising evidence?
4. Am I integrating critical appraisals into my practice?
5. Have I done any audits of my diagnostic, therapeutic, or other performances, including measures of patient satisfaction?

Outcome measures such as the DASH (Disability of Arm, Shoulder, and Hand), LEFS (Lower Extremity Functional Scale), and Oswestry Low Back Pain Disability Questionnaire are helpful tools for assessing therapeutic performance. Interestingly, estimates suggest
that only about 50% of physical therapists in the United States use standardized tools for measures of outcomes. A challenge for physical therapists and other health care professionals is to remain open and flexible to new ways of practicing. As part of a community, a movement of people who are exploring, discussing, sharing, and experiencing new understandings of how to heal and prime the human body, we need to remain open to change. Things that have been said, done, taught, and written may need to be revisited, rethought, and reworked. The previously listed questions asked by family doctors regarding patient care. Physical therapists need.

CONCLUSIONS
A sound approach to sports physical therapy practice and clinical decision-making is the role of all sports therapists. Practicing EBM will help the sports physical therapist deal with the increasingly insurmountable growth of medical literature that is published. Additionally, practicing EBM should allow clinicians an avenue for excellence and development in clinical practice. Clinician expertise and patient values are both valued components of the decision making process of EBM and EBP. Sports physical therapist can adopt EBM and EBP approaches in their clinic, but will face challenges with less-than ideal evidence. The less than ideal evidence is changing due to excellent sports related physical therapy journal such as IJSPT, JOSPT, and due to efforts by the APTA with the promotion of PT Now and future sources to increase knowledge and awareness of the critical evidence available for therapists. We must all continue to work together in a goal toward developing evidence. Partnerships between researchers and clinicians will continue to help the lives of our patient athletes and achieve the goal of learning new, better, quicker, and more successful methods to return our athletes to their recreational or competitive sports.

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ABSTRACT

Levels of evidence allow clinicians to appreciate the quality of a particular research paper quickly. The levels are generally set out in a hierarchical order, which is based largely upon the experimental design. While there are ideal designs for studies examining the effects of interventions, risk factors for a clinical condition or diagnostic testing, in most instances researchers have had to make compromises and these subsequently decrease the quality of their work. This paper provides information concerning how those compromises relate to subsequent levels that are given to a piece of research. It also provides an understanding of issues related to evaluating papers, and suggest ways in which the reader might discern how relevant a paper might be to one’s clinical practice.

Key words: levels of evidence, research design, study quality
INTRODUCTION
During the 1990s, the term evidence based medicine (EBM) became notably more apparent in research and clinical literature. As the name suggests, it referred to examining the research evidence for making clinical decisions, and as such it was more firmly grounded in the assessment of the science supporting clinical decision-making, rather than a reliance on the experiences and subjective perceptions of so called authorities or experts. For EBM to have credibility, there needed to be a systematic manner in which clinical research was assessed, and this demanded the development of levels of evidence to ultimately appreciate and assess the quality of research available in answering a particular clinical question. Initially, efforts on assessment of quality were focused upon intervention studies, examining the degree of effectiveness of treatments for clinical disorders, however, in recent years such efforts have expanded to include other key clinical research areas such as diagnosis and risk factors. The purpose of this paper is to describe the key elements that determine the levels of evidence that subsequently allow the most appropriate or efficacious clinical decision to be made for the patient.

STUDY DESIGN HIERARCHIES PROVIDE AN INITIAL STARTING POINT
Physical Therapists are often interested in studies that involve treatment interventions, identifying risk factors for succumbing to an injury or disease, and diagnosis of clinical conditions. In each of these areas, there are a number of different study designs that can be implemented. These designs may dictate the potential importance of the studies findings in its field. The design that a researcher chooses should be that which most appropriately answers the question being posed. However in many cases, it reflects the resources that researchers have at their disposal and the practicalities of undertaking the research. Resources required for studies may involve physical space and equipment, expertise in data collection, administrative processing of data, statisticians for analyzing data, and patient availability. In most cases, a researcher does not have the opportunity to cover all of these resources to the maximum level possible. Because of this, compromises are made and these often affect the choice of design to be utilised during the research process.

In studies concerning interventions, risk factors and diagnosis, the strength of an experimental paper’s design is rated upon a scale that has 4-5 levels and may be regarded as a hierarchy with level 1 being the highest. In the current paper, the hierarchies presented are based on those recommended by the National Health and Medical Research Council of Australia. However, there are others and they generally follow the same pattern, being different only in the alphanumeric nomenclature given to the levels of the hierarchy (eg: 1a or IIa etc). While one design may be high in the hierarchy for a particular question to be answered, it may not fare so well for a different question. For instance, while a prospective cohort study may be very effective at identifying risk factors, such a design does not provide professionals with the best evidence of a treatment’s effect on a particular clinical condition. For the latter, a randomised controlled trial (RCT) would be more appropriate. Thus, it is important to recognise that different study designs have particular features that may make them advantageous for answering a certain type of research question.

If possible, always look for systematic reviews when searching the literature. A Level 1 rating is reserved for a systematic review of the experimental papers. In such a paper, the quality of the designs and the findings of all the individual experimental papers are assessed in a systematic manner to provide an overall assessment or answer for a particular study question. However, it should be noted that not all systematic reviews automatically reach Level 1. If the papers that were reviewed were primarily of studies with poor designs, then the strength of evidence for the providing the answer to the question posed is lower, and the systematic review no matter how well it was conducted will not receive Level 1 status. Thus, the experimental papers upon which the review is based should determine the validity and strength of the review’s findings.

Even when a systematic review has utilised papers with the strongest possible designs, the professional needs to appreciate a number of other factors that will influence its importance. These include the number of papers that have been reported upon, and the consistency of the results across papers. One should also appreciate the degree to which the findings apply to
the clinical population of interest and what the implications are in respect to applying them in clinical practice, that is, could they be reasonably implemented. On the above-mentioned scale, the highest quality experimental designs are rated with a Level 2 and lesser-rated designs receive Levels that decline to 4-5.

**Interventions**

For studies examining treatment interventions, randomised controlled trials (RCTs) provide Level II evidence, the strongest level of evidence below a systematic review. Not surprisingly, the two key criteria for these study designs are the incorporation of at least one control group and the randomisation of participants. Without a control group, it is impossible to determine how participants would have changed over time without the experimental intervention. For instance, changes may have occurred due to disease progression or spontaneous recovery. The specific conclusions that can be drawn regarding the experimental intervention are critically dependent on what the control group receives. For example, researchers could compare the effects of icing on acute knee pain to a control group who received no specific intervention, or they could give the control group a bag of peas that are at room temperature to place over their knee for the same period of time. In the first example, the only conclusion that could be drawn is that icing is more effective at reducing pain than no treatment, whereas in the latter example, by controlling for effects associated with receiving a physical intervention to the knee and for the time of application, a researcher could therefore make more specific conclusions regarding the effects of ice itself. In terms of randomisation, the crucial criterion for a RCT is that neither the participant nor the experimenter should be able to predict which group the participant will be allocated to. Commonly accepted randomisation procedures include a coin toss, random number generator, drawing group allocation from an envelope. While researchers may design more complex procedures to ensure that group characteristics are matched on important factors and that participant numbers are balanced between groups, the final determination of group allocation for each participant should be due to chance alone.

One step down from an RCT is a pseudo-RCT, which provides Level III-1 evidence. In these study designs, there is still an appropriate control group but group allocation is not strictly randomised. Group allocation in pseudo-RCTs is dictated by a set rule such as date of birth or participant number. These are weaker randomisation procedures as the experimenter can have knowledge of the group to which a participant will be assigned. The ability to predict group allocation introduces bias into the study as this knowledge can affect the decision about whether to enter the participant into the trial, which may bias the results of the trial overall.

The next level of evidence, Level III-2, incorporates non-randomised controlled trials and two types of observational studies. Non-randomised controlled trials have marked group selection bias. For example, participants may allocate themselves into groups by choosing to receive a treatment, or participants presenting to a particular treatment provider might be always allocated to the experimental intervention and those that present to another treatment provider might receive a control intervention only. Observational designs include cohorts in which a group of people who are exposed to a particular intervention are followed over time and their health outcomes compared to a similar group of people who were not exposed to the intervention. Another example of an observational study is the case-control design, in which people with a selected condition are identified and their history of exposure to an intervention is compared to a similar group of people who do not have the condition. In all of these study designs, the researchers are not in control of group randomisation and thus the potential for selection bias is substantially higher than in RCTs. This selection bias means that there will be an inherent risk that confounding factors, or factors other than the intervention of interest, are influencing the results of the study. However, it is important to recognise that there are some research questions and interventions to which researchers cannot apply the principles of randomisation and have subjects assigned to different groups, e.g. abortion or obesity, or whether parachutes are an effective life saver. In such situations, the observational designs are the best or only alternative, and hence they can be extremely valuable.

The final group of studies providing Level III evidence (Level III-3) are comparative studies with non-controlled designs. These are non-randomised studies...
where a group of people receiving the intervention of interest are compared with previous or historical information, or to another group receiving another intervention in another study. The key limitation of these studies is the lack of a concurrent control group, and thus it is not possible to determine the specific effects of the intervention in the population as there is not a suitable comparative group. The attempt to make up for the lack of a control group by comparing to historical data or other studies provides an improvement over non-comparative studies (see case series below), but is still limited. For example, comparison to historical data on disease progression may be confounded by changes in disease management, specific characteristics of the participants tested, or variations in the assessment of outcome measures.

The lowest level of evidence (Level IV) is provided by case series that have no comparison group. These are usually pre-test - post-test comparisons of outcomes following an intervention in a single group. Obviously, the lack of a control comparison severely limits the strength of the findings and the conclusions that could be drawn. These study designs will often incorporate the addition of a second pre-test measure following a baseline, control period. This control period and additional baseline measure marginally strengthen the design of the study by enabling participants to serve “as their own control”. Case series study designs are commonly used for feasibility studies to demonstrate the potential efficacy, safety, or practicality of an intervention before implementation in a larger, more robust study.8

**Risk factors**

In the intervention section above, we described observational study designs such as the prospective cohort and the case control. While not the best choice of design for examining interventions where subjects can be randomised into groups, they can be very powerful in the study of risk factors associated with the development of clinical conditions.9 In the aetiology hierarchy, the strongest of the observational studies is the prospective cohort receiving level II. As the name suggests, it follows a group of similar individuals (eg: forestry workers) over time to examine whether a particular factor (eg: vibration from chain saw use) influences the occurrence of an outcome (osteoarthritis in the hand). A key point is that the occurrence of the outcome has not occurred at the commencement of the study. Such a design allows a consistent measurement of exposure across all the study participants and consistent measurement of the criteria that determines the outcome (eg: the presence of osteoarthritis in the hand). Cohort designs can be prospective or retrospective with the latter being at a lower hierarchal level. The key difference is that the data related to the exposure and the outcome has already been collected in the retrospective design. In many instances, the risk factor and/or outcome of interest was not the reason for the original study.10 For example, while a prospective study may have primarily been run to examine vibration levels as a risk factor for osteoarthritis of the hand in forestry workers, data might also have been collected on specific safety procedures and injuries that occurred in this cohort. Such data can be linked retrospectively and associations between variables can provide important findings. However, because the retrospective study was not the original intention, the same degree of standardisation of the data collection procedures and the precision in which they were collected is unlikely to have been undertaken and therefore the design is not as strong as a prospective study.

At the next level in the hierarchy of designs for examining risk factors is the case-control study. In this design two groups are identified, one that has a clinical condition of interest, and another that does not. For instance, a group of forestry workers with osteoarthritis of the hand would be the case group and they would be compared to a group of forestry workers without osteoarthritis of the hand. That comparison might involve examining potential physical risk factors, (e.g. tools used, tasks performed, times and volume of work) that were undertaken by both groups over a specified time to highlight a risk factor or set of factors that are different across the groups. This design is weaker than the cohort design as only the outcome (osteoarthritis of the hand) has the potential to have been measured in a standardised and precise manner.10 Even then, one of the most notable criticisms of this design is that the criteria for being included in either the control or case groups may be insufficient to accurately represent those of the wider population with and without the condition of interest.9 This is particularly so, when the case-control
design is targeting risk factors for a rare condition. Characterising risk factors associated with rare conditions is a key strength of the case control. The alternative, if one were to use a prospective cohort, means waiting for sufficient cases to contract a disease so that its risk factors might be characterised well, and that may never eventuate.

Cross sectional study designs and case series form the lowest level of the aetiology hierarchy. In the cross sectional design, data concerning each subject is often recorded at one point in time. For instance, a questionnaire might be sent to a district where forestry is a predominant industry. It might ask about the presence of osteoarthritis in the hand. In doing so, the prevalence of the disorder can be established. Some information related to exposure might also be collected and associations might be observed, but it is difficult to be confident in the validity of these associations. Thus, information gained from the cross-sectional study is often a starting point that provides the impetus to use a more powerful design to substantiate the initial findings.

Diagnosis

For diagnostic studies, the basic design utilized is very similar across most studies, and the higher levels of the hierarchy are based on meeting specific methodological criteria within that design. To receive Level II strength, the design is usually a prospective cohort, and the comparison it makes between a diagnostic test and a reference standard requires the following criteria: All subjects should receive the reference standard, and that standard should be the best evidence available for determining whether the condition of interest is present. For studies, involving primary care, this will often be a scanning or electrophysiological procedure and might also include an anaesthetic block, while in studies involving tertiary care patients, the reference standard is often what is observed at surgery. The diagnostic test and the reference standard should also be completely independent of one another. It is crucial that the reference standard and the diagnostic tests are clearly described so that others can replicate them. The persons performing the diagnostic tests on the patients should not have knowledge of the results of the reference standard and similarly those performing the reference standard should have no knowledge of the results of the diagnostic test. The patients participating in the study must be well described, and represent those with mild as well as severe levels of the condition of interest who are recruited in a consecutive manner, and at the end of the study they are all accounted for.

Studies where the subjects are not consecutively recruited are assigned level III-1 strength. When the criteria relating to reference standards are partially compromised, a study is regarded as level III-2. When a study uses a group of subjects that don't include a wide spectrum of those likely to have the condition, or don't identify specific potential sub-groupings that might affect the results, it is assigned level III-3. Such studies are often case-control designs where there are narrow criteria for inclusion in either the case or control groups, which can ultimately affect the generalizability of the results. The lowest level (IV) is reserved for those studies that lack a reference standard.

IRRESPERCTIVE OF DESIGN, THE QUALITY OF STUDIES IS IMPORTANT

While hierarchies provide the professional with a guide to how well a study design might answer a question, one must also consider how well that design has been implemented. Within each design, there is a set of criteria that should be subscribed to, to make the design as robust as possible. The RCT may be at level II on the design hierarchy, and hence a good choice of design for studies examining the effects of an intervention. However, if that RCT has insufficient subject numbers to detect a reasonable difference across groups or blinding of subjects was not undertaken, or there were notable dropouts, then one should question the value of the results from that study, despite the design being the most appropriate. A study with a design lower on the hierarchy that has been undertaken well may provide more valid information.

There are numerous scales or checklists to choose from within the literature to assess the quality of individual research studies across the domains of interventions, aetiology, and diagnosis. The key sources of bias that might threaten the validity of the results of studies generally relates to the selection of patients, randomization, therapeutic regime, withdrawals, blinding, and
statistical analyses. Be aware that some checklists are extremely extensive and include questions on issues that may not actually have the potential to bias the results, which is the primary reason for your assessment of the methodological quality.

The answers to checklist questions concerning methodological issues may be categorical (e.g.: bias present or not) or may be graded (e.g.: 1 to 4). In some instances, the answers are weighted according to how important the checklist developer thought the bias might affect the results. Generally, the weightings of checklist questions have been subjectively applied with little if any empirical support, and subsequently total scores across checklists can be quite different. Where weighting has not been applied across questions, the assumption is that all issues are of the same value and that is arguably not so. In light of these potential issues, at the Cochrane Collaboration Higgins et al have indicated that readers refrain from giving an overall score to a paper on its methodological quality, but rather to identify whether methodological quality criteria have been met or not met, and in the latter case, how relevant the issue might be to the size of the effects observed in the study. This strategy makes it much harder for an individual to discern whether a particular paper is one that should be given more or less consideration, in respect to clinical decisions to be made. If clinicians are expected to assess the merits of individual experimental papers, this is an area that must be addressed further for more types of studies. Key sources of questionnaires for assessing the quality of intervention, risk factor and diagnostic studies are provided by Higgins et al, Hayden et al, Bossuyt et al, and Whiting et al, respectively.

**APPLYING WHAT IS FOUND IN THE LITERATURE TO CLINICAL SCENARIOS**

Assuming that papers have been identified that perform well from a methodological perspective, and their designs are well placed on the hierarchy for answering a particular question, finding papers that include participants who are similar to the patient(s) of interest to the professional is important. Such consideration should include an assessment of the level of severity of the groups under study (e.g.: mildly, moderately or severely affected), together with the amount of treatment they were being given, and the timing of that treatment within their disease/injury healing process. Furthermore, check when the researchers made their assessments to determine change in the participant's status. Ask whether these are realistic time points to do an assessment, and if the follow up was appropriate to determine the longer-term effects.

It is also important that clinicians look beyond the treatment effect of an intervention to get a balanced view of its merits. Consideration should be made not only of the benefits but also the potential harm associated with a particular treatment. For instance, a new regime for treating acute muscle tears might be developed and shown in a well-conducted RCT to allow players to return to sports much earlier than anything currently available. However, that same regime may induce side effects, perhaps a greater likelihood of the injury recurring 6-12 months later due to the laying down of excessive scar tissue in the early stages of the rehabilitation regime. Examination of such points will allow the professional to make a better judgement concerning the relevance of the papers to the clinical decision at hand.

**GUIDELINES PROVIDE A SYSTEMATIC REVIEW AND A SET OF RECOMMENDATIONS**

Based on the information presented above, it would seem a monumental task for therapists to assess a series of individual papers and thereafter make an informed decision concerning every clinical problem that they face, particularly those where the patient is atypical, and does not resemble the subjects presented in studies. To make the task easier, guidelines have been developed to answer specific clinical problems/questions and provide recommendations. Because of the resources required, guidelines are usually initiated by organisations such as specialist groups in a field of medicine/allied health or a national health agency. These organisations convene a guidelines panel that is usually composed of scientists, clinical specialists, statisticians, patients and lay people, and they are supported by data analysts and administrators. Their first step is to identify the question of interest and the key outcomes associated with that question. They then assess systematic reviews (Level 1 evidence in the hierarchy) that have been previously published or specifically undertake their own systematic review. In doing so, they provide a summary of the quality of the research...
undertaken, the consistency of the results across studies, the magnitudes of the intervention's effects observed in patient subgroups, the benefits versus the potential harm associated with a treatment, and whether the health benefits of a treatment are worth the costs of providing them. Most importantly though, guidelines include recommendations and these are often quite definitive, being categorised as ‘strong’ or ‘weak’. Guyatt et al describe these as reflecting a trade off between the benefits of treatment against the burdens of receiving it together with its risks; while taking into account the accuracy and strength of the data supporting the intervention. If the data analysed from experimental papers indicates that an intervention has a large effect and the risks and burdens associated with the treatment are low, then a strong recommendation can be made to implement it. Where there are inconsistencies in findings or small treatment effects or notable risks, the recommendation for the treatment/intervention might be regarded as ‘weak’, and the patient's particular circumstances may then play a greater role in whether a particular treatment is implemented.

Given the extent and thoroughness behind the construction of guidelines and the inclusion of recommendations, they are an important source for guiding clinical decision making and should be searched for early in your examination of the literature.

THINK BEYOND THE SCIENCE

While the current paper has focused upon the quantitative assessment of evidence, it cannot be regarded as the sole means by which professionals make clinical decisions. It is important that therapists continue to appreciate the individuality of each patient and the personal circumstances that they bring with their pathophysiological issues. While at present, qualitative research does not have a formal place in levels of evidence, there is without doubt evidence for its importance in providing insights into patients’ viewpoints on how the clinical condition and its treatment has influenced the lives that they lead.

Therefore, professionals must continue to value highly how we interact and react to each patient's situation, continually striving to be effective listeners and communicators, as well as being advocates of the best research evidence to help all patients improve the quality of their lives.

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<th>Table 1. Key Points summary.</th>
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<tr>
<td><strong>Key Points Summary:</strong></td>
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<tr>
<td>✤ Different types of questions require different research designs.</td>
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<td>✤ Look for clinical guidelines and systematic reviews first.</td>
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<td>✤ Consider the hierarchy of designs within diagnostic, intervention, and risk factor studies.</td>
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<td>✤ Consider the quality of papers irrespective of the design.</td>
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<tr>
<td>✤ Assess how well the subjects recruited in studies match your patient’s characteristics.</td>
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<td>✤ Be aware of not only the benefits of treatments but also their potential risks.</td>
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<tr>
<td>✤ Don’t forget to assess the patient’s circumstances, and how it might influence your evidence-based clinical recommendations to them.</td>
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3. NHMRC. NHMRC additional levels of evidence and grades for recommendations for developers of guidelines. Available at www.nhmrc.gov.au/guidelines/publications


ABSTRACT
Research is designed to answer a question or to describe a phenomenon in a scientific process. Sports physical therapists must understand the different research methods, types, and designs in order to implement evidence-based practice. The purpose of this article is to describe the most common research designs used in sports physical therapy research and practice. Both experimental and non-experimental methods will be discussed.

Key words: Research design, research methods, scientific process
INTRODUCTION
Evidence-based practice requires that physical therapists are able to analyze and interpret scientific research. When performing or evaluating research for clinical practice, sports physical therapists must first be able to identify the appropriate study design. Research begins by identifying a specific aim or purpose; researchers should always attempt to use a methodologically superior design when performing a study. Research design is one of the most important factors to understand because:

1. Research design provides validity to the study;
2. The design must be appropriate to answer the research question; and
3. The design provides a “level of evidence” used in making clinical decisions.

Validity
Research study designs must have appropriate validity, both internally and externally. Internal validity refers to the design itself, while external validity refers to the study's applicability in the real world. While a study may have internal validity, it may not have external validity; however, a study without internal validity is not useful at all.

Most clinical research suffers from a conflict between internal and external validity. Internally valid studies are well-controlled with appropriate designs to ensure that changes in the dependent variable result from manipulation of an independent variable. Well-designed research provides controls for managing or addressing extraneous variables that may influence changes in the dependent variable. This is often accomplished by ensuring a homogenous population; however, clinical populations are rarely homogenous. An internally-valid study with control of extraneous variables may not represent a more heterogeneous clinical population; therefore, clinicians should always consider the conflict between internal and external validity both when choosing a research design and when applying the results of research on order to make evidence-based clinical decisions.

Furthermore, research can be basic or applied. Basic science research is often done on animals or in a controlled laboratory setting using tissue samples, for example. Applied research involves humans, including patient populations; therefore, applied research provides more clinical relevance and clinical application (i.e., external validity) than basic science research.

One of the most important considerations in research design for internal validity is to minimize bias. Bias represents the intentional or unintentional favoring of something in the research process. Within research designs, there are 5 important features to consider in establishing the validity of a study: sample, perspective, randomization, control, and blinding.

- Sample size and representation is very important for both internal and external validity. Sample size is important for statistical power, but also increases the representativeness of the target population. Unfortunately, some studies use a ‘convenience sample’, often consisting of college students, which may not represent a typical clinical population. Obviously, a representative clinical population can provide a higher level of external validity than a convenience sample.

- In terms of perspective, a study can be prospective (before the fact) or retrospective (after the fact). A prospective study has more validity because of more control of the variables at the beginning of and throughout the study, whereas a retrospective study has less control since it is performed after the end of an event. A prospective design provides a higher level of evidence to support cause-and-effect relationships, while retrospective studies are often associated with confounding variables and bias.

- Random assignment to an experimental or control group is performed to represent a ‘normal distribution’ of the population. Randomization reduces selection bias to ensure one group doesn’t have an advantage over the other. Sometimes groups, rather than individual subjects, are randomly assigned to an experimental or control group; this is referred to as “block randomization.” Sample bias can also occur when a “convenience sample” is used that might not be representative of the target population. This is often seen when healthy, college-aged students are included, rather than a representative sample of the population.

- A control group helps ensure that changes in the dependent variable are due to changes in the
independent variable, and not due to chance. A
control group receives no intervention, while the
experimental group receives some type of inter-
vention. In some situations, a true control group is
not possible or ethical; therefore, “quasi-experi-
mental” designs are often used in clinical research
where the control group receives a “standard treat-
ment.” Sometimes, the experimental group can be
used as it's “own control” by testing different con-
ditions over time.

- Blinding (also known as “masking”) is performed to
minimize bias. Ideally, both the subjects and the
investigator should be blinded to group assignment
and intervention. For example, a “double-blind” study
is one in which the subjects are not aware if they are
receiving the experimental intervention or a pla-
cebo and at the same time, and the examiner is not
aware which intervention the subjects received.

While considering these 5 features, a large sample
size of patients, prospective, randomized, controlled,
double-blinded clinical outcome study would likely
provide the best design to assure very high internal
and external validity.

**Design**

Most research follows the “scientific method”. The
scientific method progresses through four steps:

1. Identification of the question or problem;
2. Formulation of a hypothesis (or hypotheses);
3. Collection of data; and
4. Analysis and interpretation of data.

Different research designs apply are used to
answer a question or address a problem. Different
authors provide different classifications of research
designs.¹⁻⁴

Within the scientific method, there are 2 main clas-
sifications of research methodology: experimental
and non-experimental. Both employ systematic col-
lection of data. Experimental research is used to
determine cause-and-effect relationships, while non-
experimental is used to describe observations or
relationships in a systematic manner. Both experi-
mental and non-experimental research consist of
several types and designs. (Table 1)

**Experimental Methods**

Experimental methods follow the scientific method
in order to examine changes in one variable by
manipulating other variables to attempt to establish
cause-and-effect. The dependent variable is mea-
sured under controlled conditions while controlling
for confounding variables. It is important to remem-
ber that statistics do not establish cause-and-effect;
rather, the design of the study does. Experimental
statistics can only reject a null hypothesis and iden-
tify variance accounted for by the independent vari-
able. Thomas et al.⁴ provide three criteria to establish
cause-and-effect:

1. Cause must precede effect in time;
2. Cause and effect must be correlated with each
other; and

<table>
<thead>
<tr>
<th>Table 1. Research Designs.</th>
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<tbody>
<tr>
<td><strong>Method</strong></td>
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<tr>
<td><strong>Type</strong></td>
</tr>
<tr>
<td>Design</td>
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</table>
3. Relationship cannot be explained by another variable.

There are 3 elements of research to consider when evaluating experimental designs: groups, measures, and factors. Subjects in experimental research are generally classified into groups such as an experimental (those receiving treatment) or control group. Technically speaking, however, “groups” refers to the treatment of the data, not how the treatment is administered. Groups are sometimes called “treatment arms” in order to denote subjects receiving different treatments. True experimental designs generally use randomized assignment to groups, while quasi-experimental research may not.

Next, the order of measurements and treatments should be considered. “Time” refers to the course of the study from start to finish. Observations, or measurements of the dependent variables, can be performed one or several times throughout a study. The term, “repeated measures” denotes any measurement that is repeated on a group of subjects in the study. Repeated measures are often used in pseudo-experimental research when the subjects act as their own control in one group, while true experimental research can use repeated measurements of the dependent variable as a single factor (“time”).

Since experimental designs are used to identify changes in a dependent variable by manipulating an independent variable, “factors” are used. Factors are essentially the independent variables. Individual factors can also have several levels. Single-factor designs are referred to as “one-way” designs with one independent variable and any number of levels. One-way designs may have multiple dependent variables (measurements), but only one independent variable (treatment). Studies involving more than one independent variable are considered “multi-factorial” and are referred to as “two-way” or “three-way” (and so on) designs. Multi-factorial designs are used to investigate interactions within and between different variables. A “mixed design” factorial study includes 2 more independent variables with one repeated across all subjects and the other randomized to independent groups. Figure 1 is an example of a 2-way repeated measures design including a true control group.

Factorial designs are denoted with numbers representing the number of levels of each factor. A two-way factorial (2 independent variables) with 2 levels of each factor is designated by “2 × 2”. The total number of groups in a factorial design can be determined by multiplying the factors together; for example, a 2 × 2 factorial has 4 groups while a 2 × 3 × 2 factorial has 12. Table 2 describes the differences in factorial designs using an example of 3 studies examining strength gains of the biceps during exercise. Each factor has multiple levels. In the 1-way study, strength of the biceps is examined after performing flexion or extension with standard isotonic resistance. In the 2-way study, a 3-level factor is added by comparing different types of resistance during the same movements. In the 3-way study, 2 different intensity levels are added to the design.

Statistical analysis of a factorial design begins by determining a main effect, which is an overall effect of a single independent variable on dependent variables. If a main effect is found, post-hoc analysis examines the interaction between independent variables (factors) to identify the variance in the dependent variable.

<table>
<thead>
<tr>
<th>Experimental Group</th>
<th>Pre-Test</th>
<th>Post-Test</th>
<th>TIME INTERACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Group</td>
<td></td>
<td></td>
<td>Within groups</td>
</tr>
<tr>
<td>GROUP INTERACTION</td>
<td></td>
<td></td>
<td>Between groups</td>
</tr>
</tbody>
</table>

Figure 1. Two-way repeated measures experimental design to determine interactions within and between groups.
As described in Table 1 previously, there are 2 types of experimental designs: true experimental and quasi-experimental.

True Experimental Designs
True experimental designs are used to determine cause-and-effect by manipulating an independent variable and measuring its effect on a dependent variable. These designs always have at least 2 groups for comparison.

In a true experimental design, subjects are randomized into at least 2 independent, separate groups, including an experimental and “true” control. This provides the strongest internal validity to establish a cause-and-effect relationship within a population. A true control group consists of subjects that receive no treatment while the experimental group receives treatment. The randomized, controlled trial design is the “gold standard” in experimental designs, but may not be the best choice for every project.

Table 3 provides common true experimental designs that include 2 independent, randomly assigned groups and a true control group. Notation is often used to illustrate research designs:

<table>
<thead>
<tr>
<th>Design</th>
<th>Factor A (2 levels): Exercise Movement (Flexion and Extension)</th>
<th>Factor B (3 levels): Resistance Type (Isotonic, Isokinetic, Elastic)</th>
<th>Factor C: (2 levels) Intensity (High and Low)</th>
</tr>
</thead>
</table>

Quasi-Experimental Designs
Clinical researchers often find it difficult to use true experimental designs with a ‘true’ control because it may be unethical and sometimes illegal to withhold treatment within a patient population. In addition, clinical trials are often affected by a conflict between internal and external validity. Internal validity requires rigorous control of variables; however, that control does not support real-world generalizability (external validity). As previously described, clinical researchers must seek balance between internal and external validity.

Quasi-experimental designs are those that do not include a true control group or randomization of subjects. While these types of designs may reduce the internal validity of a study, they are often used to maximize a study’s external validity. Quasi-experimental designs are used when true randomization or a true control group is unethical or difficult. For example, a ‘pseudo-control’ group may include a group of patients receiving traditional treatment rather than a true control group receiving nothing.

Block-randomization or cluster grouping may also be more practical when examining groups, rather than individual randomization. Subjects are grouped by similar variables (age, gender, etc) to help control for extraneous factors that may influence differences between groups. The block factor must be related to dependent variable (i.e., the factor affecting response to treatment).

A cross-over or counterbalanced design may also be used in a quasi-experimental study. This design is often used when only 2 levels of an independent variable are repeated to control for order effects. A cross-over study may require twice as long since both groups must undergo the intervention at different times. During the cross-over, both groups usually go through a ‘washout’ period of no intervention to be sure prolonged effects are not a factor in the outcome.

Examples of quasi-experimental designs can include both single and multiple groups (Table 4). Quasi-experimental designs generally do not randomize group assignment or use true control groups. (Note: One-group pre-post test designs are sometimes classified as “pre-experimental” designs.)

Single-subject designs are also considered quasi-experimental as they draw conclusions about the effects of a treatment based on responses of single patients.
### Table 3. *Common true experimental designs.*

<table>
<thead>
<tr>
<th>True Experimental Design</th>
<th>Brief Description</th>
<th>Notation Example</th>
</tr>
</thead>
</table>
| Pre-post test control group (one-way factorial)           | Experimental and control groups with pre- and post test; only experimental group receives treatment | \( n_1: O_0 - T - O_1 \)  
   \( n_0: O_0 - O_1 \) |
| Post-test only control group                              | Same as above, but no pre-test                                                   | \( n_1: T - O_1 \)  
   \( n_0: O_1 \) |
| Multi-factorial (2-way, 3-way, etc)                       | multiple experimental groups with one true control group                          | \( n_1: O_0 - T_1 - O_1 \)  
   \( n_2: O_0 - T_2 - O_1 \)  
   \( n_3: O_0 - T_3 - O_1 \)  
   \( n_0: O_0 - O_1 \) |
| Mixed Design                                              | 1 experimental and 1 true control group with repeated measures                   | \( n_1: O_0 - T_1 - O_1 - O_2 \)  
   \( n_0: O_0 - O_1 - O_2 \) |

\( n = \) subjects in a group (\( n_1 \) refers to experimental group while \( n_0 \) refers to control group)  
\( T = \) treatment (\( T_1 \) refers to sequential treatments)  
\( O = \) observation (\( O_0 \) refers to baseline, \( O_1 \) refers to sequential observations)

### Table 4. *Quasi-Experimental designs.*

<table>
<thead>
<tr>
<th>Quasi Experimental Design</th>
<th>Brief Description</th>
<th>Notation Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>One group pre-post test</td>
<td>1 group evaluated before and after intervention</td>
<td>( n_1: O_0 - T - O_1 )</td>
</tr>
<tr>
<td>One-way repeated measures</td>
<td>1 group evaluated multiple times (with or without baseline)</td>
<td>( n_1: O_0 - T_1 - O_1 - T_2 - O_2 )</td>
</tr>
</tbody>
</table>
| Two-group pre-post test (no true control)                   | 2 groups evaluated before and after intervention with pseudo-control or no control | \( n_1: O_0 - T_1 - O_1 \)  
   \( n_2: O_0 - T_2 - O_1 \) |
| Two-way repeated measures (2x3)                             | 2 groups, multiple observations, no true control                               | \( n_1: O_0 - T_1 - O_1 - O_2 \)  
   \( n_2: O_0 - T_2 - O_1 - O_2 \) |
| Non-equivalent pre-post test control                        | 2 groups not randomized; often healthy versus patient groups                    | \( n_1: O_0 - T - O_1 \)  
   \( n_0: O_0 - O_1 \) |
| Historical control                                          | Control group was evaluated earlier as part of a previous study               | \( n_1: O_0 - T_1 - O_1 \)  
   \( n_0: O_0 \) |
| Cross-over design                                           | 2 groups switch intervention after wash-out period (X)                         | \( n_1: O_0 - T_1 - O_1 - O_2 - X \)  
   \( n_2: O_0 - O_1 - O_2 - X \)  
   \( O_3 - T_1 - O_4 \)  
   \( X \) denotes the washout |
| Time-series design                                          | Multiple measures before and after treatment, usually used for behavioral or community interventions | \( n_1: O_0 - T_1 - O_1 - O_2 \)  
   \( n_2: O_0 - T_1 - O_1 - T_1 - O_2 \) |

\( n = \) subjects in a group (\( n_1 \) refers to experimental group while \( n_0 \) refers to control group)  
\( T = \) treatment (\( T_1 \) refers to sequential treatments)  
\( O = \) observation (\( O_0 \) refers to baseline, \( O_1 \) refers to sequential observations)
under controlled conditions. These designs are used when withholding treatment is considered unethical or when random assignment is not possible or when it is difficult to recruit subjects as is commonly seen in rare diseases or conditions. Single subject designs have 2 essential elements: design phases and repeated measures. Design phases include baseline and intervention phases. The baseline measure serves as a ‘pseudo-control.” Repeated measurement over time (for example, during each treatment session) can occur during the baseline and intervention phases. Common single-subject designs are commonly denoted by the letters ‘A’ (baseline phases) and ‘B’ (intervention phases): A-B; A-B-A; and A-B-A-B. Other single-subject designs include withdrawal, multiple baselines, alternating treatment, multiple treatment, and interactive design. For more detailed descriptions on single subject designs, see Portney and Watkins.

Non-Experimental Methods
Studies involving non-experimental methods include descriptive, exploratory, and analytic designs. These designs do not infer cause-and-effect by manipulating variables; rather, they are designed to describe or explain phenomena. Non-experimental designs help provide an early understanding about clinical conditions or situations, without a full clinical study through systematic collection of data.

Descriptive Designs
Descriptive designs are used to describe populations or phenomena, and can help identify groups and variables for new research questions. Descriptive designs can be prospective or retrospective, and may use longitudinal or cross-sectional methods. Phenomena can be evaluated in subjects either over a period time (longitudinal studies) or through sampling different age-grouped subjects (cross-sectional studies). Descriptive research designs are used to describe results of surveys, provide norms or descriptions of populations, and to describe cases. Descriptive designs generally focus on describing one group of subjects, rather than comparing different groups.

Surveys. Surveys are one of the most common descriptive designs. They can be in the form of questionnaires or interviews. The most important component of an effective survey is to have an appropriate sample that is representative of the population of interest. There are generally 2 types of survey questions: open-ended and closed-ended. Open-ended questions have no fixed answer, while closed-ended questions have definitive answers including rank, scale, or category. Investigators should be careful not to lead answers of subjects one way or another, and to keep true to the objectives of the study. Surveys are limited by the sample and the questions asked. External validity is threatened, for example, if the sample was not representative of the research question and design.

A special type of survey is the Delphi technique that uses expert opinions to make decisions about practices, needs, and goals. The Delphi technique uses a series of questionnaires in successive stages called “rounds.” The first round of the survey focuses on opinions of the respondents, and the second round of questions is based on the results of the first round, where respondents are asked to reconsider their answers in context of other’s responses. Delphi surveys are common in establishing expert guidelines where consensus around an issue is needed.

Observational. A descriptive observational study evaluates specific behaviors or variables in a specific group of subjects. The frequency and duration of the observations are noted by the researcher. An investigator observing a classroom for specific behaviors from students or teachers would use an observational design.

Normative. Normative research describes typical or standard values of characteristics within a specific population. These “norms” are usually determined by averaging the values of large samples and providing an acceptable range of values. For example, goniometric measures of joint range of motion are reported with an accepted range of degrees, which may be recorded as “within normal limits.” Samples for normative studies must be large, random, and representative of the population heterogeneity. The larger the target population, the larger sample required to establish norms; however, sample sizes of at least 100 are often used in normative research. Normative data is extremely useful in clinical practice because it serves as a basis for determining the need for an intervention, as well as an expected outcome or goal.

Developmental. Developmental research helps describe the developmental change and the sequencing
of human behavior over time. This type of research is particularly useful in describing the natural course of human development. For example, understanding the normal developmental sequencing of motor skills can be useful in both the evaluation and treatment of young athletes. Developmental designs are classified by the method used to collect data; they can be either cross-sectional or longitudinal.

**Case Designs.** Case designs offer thoughtful descriptions and analysis of clinical information; they include case reports, case studies, and case series. A case report is an in-depth understanding of a unique patient, while a case study focuses on a unique situation. These cases may involve a series of patients or situations, which is referred to as a ‘case series’ design. Case designs are often useful in developing new hypotheses and contributing to theory and practice. They also provide a springboard for moving toward more quasi-experimental or experimental designs in order to investigate cause and effect.

**Qualitative.** Research measures can also be classified as quantitative or qualitative. Quantitative measures explain differences, determines causal relationships, or describes relationships; these designs include those previously discussed. Qualitative research, on the other hand, emphasizes attempting to discern process and meaning without measuring quantity. Qualitative studies focus on analysis in trying to describe a phenomenon. Qualitative research examines beliefs, understanding, and attitudes through skillful interview and content analysis. These designs are used to describe specific situations, cultures, or everyday activities. Table 5 provides a comparison between qualitative and quantitative designs.

**Table 5. Comparison of quantitative and qualitative designs (Adapted from Thomas et al. and Carter et al.)**

<table>
<thead>
<tr>
<th>Research Component</th>
<th>Qualitative</th>
<th>Quantitative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypothesis</td>
<td>Inductive, grounded</td>
<td>Deductive, set a-priori</td>
</tr>
<tr>
<td>Sample</td>
<td>Purposeful, small</td>
<td>Random, large groups</td>
</tr>
<tr>
<td>Setting</td>
<td>Natural, real-world</td>
<td>Laboratory</td>
</tr>
<tr>
<td>Data gathering</td>
<td>Researcher is primary instrument; relies on language &amp; words for data</td>
<td>Objective instrumentation; relies on numerical data</td>
</tr>
<tr>
<td>Design</td>
<td>Flexible; may change</td>
<td>Determined in advance</td>
</tr>
<tr>
<td>Data analysis</td>
<td>Descriptive interpretation</td>
<td>Statistical methods</td>
</tr>
<tr>
<td>Variable manipulation</td>
<td>Absent</td>
<td>Present</td>
</tr>
</tbody>
</table>

**Exploratory Designs**

Exploratory designs establish relationships without manipulating variables while using non-experimental methods. These designs include cohort studies, case control studies, epidemiological research, correlational studies, and methodological research. Exploratory research usually involves comparison of 2 or more groups.

**Cohort Studies.** A cohort is a group of subjects being studied. Cohort studies may evaluate single groups or differences between specific groups. These observations may be made in subjects one time, or over periods of time, using either cross-sectional or longitudinal methods.

In contrast to experimental designs, non-experimentally designed cohort studies do not manipulate the independent variable, and lack randomization and blinding. A prospective analysis of differences in cohort groups is similar to an experimental design, but the independent variable is not manipulated. For example, outcomes after 2 different surgeries in 2 different groups can be followed without randomization of subjects using a prospective cohort design.

Some authors have classified ‘Outcomes Research’ as a retrospective, non-experimental cohort design, where differences in groups are evaluated ‘after the fact’ without random allocation to groups or manipulation of an independent variable. This design would include chart reviews examining outcomes of specific interventions.

**Case Control Studies.** Case control studies are similar to cohort studies comparing groups of subjects with a particular condition to a group without the
condition. Both groups are observed over the same period of time, therefore requiring a shorter time-frame compared to cohort studies. Case control studies are better for investigations of rare disease or conditions because the sample size required is less than a cohort study. The control group (injury/disease-free) is generally matched to the injury/disease group by confounding variables consistent in both groups such as age, gender, and ethnicity.

Case control studies sometimes use “odds ratios” in order to estimate the relative risk if a cohort study would have been done. An odds ratio greater than 1 suggests an increased risk, while a ratio less than 1 suggests reduced risk.

Epidemiological Research. Studies that evaluate the exposure, incidence rates, and risk factors for disease, injury, or mortality are descriptive studies of epidemiology. According to Thomas et al, epidemiological studies evaluate “naturally occurring differences in a population.” Epidemiological studies are used to identify a variety of measures in populations (Table 6).

“Relative risk,” (RR) which is associated with exposure and incidence rates. Portney and Watkins use a “contingency table” (Table 7) to determine the relative risk and odds ratio. Usually, incidence rates are compared between 2 groups by dividing the incidence of one group by the other.

Using Table 7,

Relative Risk = \( \frac{a / (a + b)}{d / (c + d)} \)

Odds Ratio = \( \frac{a / c}{b / d} \)

With these formulas, the “null value” is 1.0. A risk or odds ratio less than 1.0 suggests reduced risk or odds, while a value greater than 1.0 suggests increased risk or odds. For example, if the risk is 1.5 in a group, there is a 1.5 times greater risk of suffering an injury in that group. Relative risk should be reported with a confidence interval, typically 95%.

Epidemiological studies can also be used to test a hypothesis of the effectiveness of an intervention on injury prevention by using incidence as a dependent variable. These studies help link exposures and outcomes with observations, and can include case control and cohort studies mentioned previously.

Correlational Studies. Correlations studies examine relationships among variables. Correlations are expressed using the Pearson’s “r” value that can range from -1 to +1. A Pearson’s “r” value of +1 indicates a perfect linear correlation, noting the increase in one variable is directly dependent on the other. In contrast, an “r” value of -1 indicates a perfect inverse relationship. An “r” value of 0 indicates that the variables are independent of each other. The most important thing to remember is that correlation does not infer causation; in other words, correlational studies can’t be used to establish cause-and-effect. In addition, 2 variables
may have a high correlation ($r > .80$), but lack statistical significance if the $p$-value is not sufficient. Finally, be aware that correlational studies must have a representative sample in order to establish external validity.

**Methodological.** The usefulness of clinical research and decision-making heavily depends on the validity and reliability of measurements. Methodological research is used to develop and test measuring instruments and methods used in practice and research. Methodological studies are important because they provide the reliability and validity of other studies. First, the reliability of the rater (inter-rater and intra-rater reliability) must be established when administering a test in order to support the accuracy of measurements. Inter-rater reliability supports consistent measurements between different raters, while intra-rater reliability supports consistent measures for the same individual rater. Reliability can also be established for instruments by demonstrating consistent measurements over time. Reliability is related to the ability to control error, and thus associated with internal validity.

Methodological studies are also used to establish validity for a measurement, which may include clinical diagnostic tests, performance batteries, or measurement devices. Measurement validity establishes the extent to which an instrument measures what it intends to measure. Different types of validity can be measured, including face validity, content validity, criterion-related validity and construct validity (Table 8).

Sports physical therapists may also be interested in the sensitivity and specificity of clinical tests. Sensitivity refers to the ability of a test to correctly identify those with a condition, while specificity refers to the ability to correctly identify those without the condition. Unfortunately, few clinical tests possess both high sensitivity and specificity.6

**Analytical Designs**

Analytical research designs are not just a review or summary, but a method of evaluating the existing research to reach a conclusion. These designs provide a synthesis of the literature for empirical and theoretical conclusions. Analytical designs explain phenomena and analyze existing data using systematic reviews and meta-analysis techniques. In contrast to systematic reviews, meta-analyses include statistical analysis of data.

**Systematic Reviews.** Systematic reviews most commonly examine the effectiveness of interventions, but may also examine the accuracy of diagnostic tools. Systematic reviews of randomized controlled trials provide the highest level of evidence possible. Systematic reviews should describe their methodology in detail, including inclusion and exclusion criteria for studies reviewed, study designs, and outcomes measures. In addition, the method of literature search should be detailed including databases, dates, and keywords used.

**Meta-Analysis.** Systematic reviews can be extended into meta-analysis if multiple studies contain necessary information and data. Meta-analysis techniques are particularly useful when trying to analyze and interpret smaller studies and studies with inconsistent outcomes. Meta-analysis of randomized controlled trials provides a high level of evidence, but may suffer in quality from heterogeneous samples, bias, outliers, and methodological differences.

Meta-analysis quantifies the results of various studies into a standard metric that allows for statistical analysis to calculate effect sizes. The effect size, calculated by "Cohen's $d$ value," is defined as a standardized value of the relationship between two variables. Effect size provides magnitude and direction of the effect of a treatment, and is determined by the difference in

<table>
<thead>
<tr>
<th>Table 8. Different types of validity in scientific research.</th>
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<tbody>
<tr>
<td><strong>Face Validity</strong></td>
</tr>
<tr>
<td><strong>Content Validity</strong></td>
</tr>
<tr>
<td><strong>Criterion-related Validity</strong></td>
</tr>
<tr>
<td><strong>Construct Validity</strong></td>
</tr>
</tbody>
</table>
means divided by the standard deviation ($\Delta M / SD$). A Cohen’s $d$ value of .2 is considered small; .5 is considered moderate, and .8 and greater is a large effect size. Confidence intervals are then reported to provide an interval of certainty.

Levels of Evidence
Research designs are often viewed in a hierarchy of evidence. These designs have been discussed in this paper, but bear repeating in the context of evidence-based practice. “Levels of Evidence” have been established by the Center for Evidence-Based Medicine in Oxford, England (Table 9) as well as other research consortiums. Each level is based on controlling as many factors (variables) as possible to confidently make conclusions without bias, the highest of which is cause-and-effect. In addition, “grades” of evidence have been established based on the quality and number of various levels of evidence to make recommendations in reviews and guidelines (Table 10). Thus, a research publication could be described and labeled using a combination of a level and a grade, such as “Level II-A” or “Level II-B”.

CONCLUSION
In conclusion, it is important for sports physical therapists to understand different research designs not only to support evidence-based practice, but also to contribute to the body of knowledge by using appropriate research designs. Clinicians should be aware of appropriate research design, validity, and levels of evidence in order to make informed clinical decisions. This commentary described the most common and relevant experimental and non-experimental designs used and encountered by sports physical therapists who contribute to and utilize evidence-based practice.

REFERENCES

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ABSTRACT

The use of an evidence-based approach to practice requires “the integration of best research evidence with clinical expertise and patient values”, where the best evidence can be gathered from randomized controlled trials (RCTs), systematic reviews and meta-analyses. Furthermore, informed decisions in healthcare and the prompt incorporation of new research findings in routine practice necessitate regular reading, evaluation, and integration of the current knowledge from the primary literature on a given topic. However, given the dramatic increase in published studies, such an approach may become too time consuming and therefore impractical, if not impossible. Therefore, systematic reviews and meta-analyses can provide the “best evidence” and an unbiased overview of the body of knowledge on a specific topic. In the present article the authors aim to provide a gentle introduction to readers not familiar with systematic reviews and meta-analyses in order to understand the basic principles and methods behind this type of literature. This article will help practitioners to critically read and interpret systematic reviews and meta-analyses to appropriately apply the available evidence to their clinical practice.

Key words: evidence-based practice, meta-analysis, systematic review

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INTRODUCTION

Sacket et al1,2 defined evidence-based practice as “the integration of best research evidence with clinical expertise and patient values”. The “best evidence” can be gathered by reading randomized controlled trials (RCTs), systematic reviews, and meta-analyses.2 It should be noted that the “best evidence” (e.g. concerning clinical prognosis, or patient experience) may also come from other types of research designs particularly when dealing with topics that are not possible to investigate with RCTs.3,4 From the available evidence, it is possible to provide clinical recommendations using different levels of evidence.5 Although sometimes a matter of debate,6-8 when properly applied, the evidence-based approach and therefore meta-analyses and systematic reviews (highest level of evidence) can help the decision-making process in different ways:9

1. Identifying treatments that are not effective;
2. Summarizing the likely magnitude of benefits of effective treatments;
3. Identifying unanticipated risks of apparently effective treatments;
4. Identifying gaps of knowledge;
5. Auditing the quality of existing randomized controlled trials.

The number of scientific articles published in biomedical areas has dramatically increased in the last several decades. Due to the quest for timely and informed decisions in healthcare and medicine, good clinical practice and prompt integration of new research findings into routine practice, clinicians and practitioners should regularly read new literature and compare it with the existing evidence.10 However, this is time consuming and therefore is impractical if not impossible for practitioners to continuously read, evaluate, and incorporate the current knowledge from the primary literature sources on a given topic.11 Furthermore, the reader also needs to be able to interpret both the new and the past body of knowledge in relation to the methodological quality of the studies. This makes it even more difficult to use the scientific literature as reference knowledge for clinical decision-making. For this reason, review articles are important tools available for practitioners to summarize and synthesize the available evidence on a particular topic,10 in addition to being an integral part of the evidence-based approach.

International institutions have been created in recent years in an attempt to standardize and update scientific knowledge. The probably best known example is the Cochrane Collaboration, founded in 1993 as an independent, non-profit organisation, now regrouping more than 28,000 contributors worldwide and producing systematic reviews and meta-analyses of healthcare interventions. There are currently over 5000 Cochrane Reviews available (http://www.cochrane.org). The methodology used to perform systematic reviews and meta-analyses is crucial. Furthermore, systematic reviews and meta-analyses have limitations that should be acknowledged and considered. Like any other scientific research, a systematic review with or without meta-analysis can be performed in a good or bad way. As a consequence, guidelines have been developed and proposed to reduce the risk of drawing misleading conclusions from poorly conducted literature searches and meta-analyses.11-18

In the present article the authors aim to provide an introduction to readers not familiar with systematic reviews and meta-analysis in order to help them understand the basics principles and methods behind this kind of literature. A meta-analysis is not just a statistical tool but qualifies as an actual observational study and hence it must be approached following established research methods involving well-defined steps. This review should also help practitioners to critically and appropriately read and interpret systematic reviews and meta-analyses.

NARRATIVE VERSUS SYSTEMATIC REVIEWS

Literature reviews can be classified as “narrative” and “systematic” (Table 1). Narrative reviews were the first form of literature overview allowing practitioners to have a quick synopsis on the current state of science in the topic of interest. When written by experts (usually by invitation) narrative reviews are also called “expert reviews”. However, both narrative or expert reviews are based on a subjective selection of publications through which the reviewer qualitatively addresses a question summarizing the findings of previous studies and drawing a conclusion.15 As such, albeit offering
interesting information for clinicians, they have an obvious author’s bias since not performed by following a clear methodology (i.e. the identification of the literature is not transparent). Indeed, narrative and expert reviews typically use literature to support authors’ statements but it is not clear whether these statements are evidence-based or just a personal opinion/experience of the authors. Furthermore, the lack of a specific search strategy increases the risk of failing to identify relevant or key studies on a given topic thus allowing for questions to arise regarding the conclusions made by the authors. Narrative reviews should be considered as opinion pieces or invited commentaries, and therefore they are unreliable sources of information and have a low evidence level.

By conducting a “systematic review”, the flaws of narrative reviews can be limited or overcome. The term “systematic” refers to the strict approach (clear set of rules) used for identifying relevant studies, which includes the use of an accurate search strategy in order to identify all studies addressing a specific topic, the establishment of clear inclusion/exclusion criteria and a well-defined methodological analysis of the selected studies. By conducting a properly performed systematic review, the potential bias in identifying the studies is reduced, thus limiting the possibility of the authors to select the studies arbitrarily considered the most “relevant” for supporting their own opinion or research hypotheses. Systematic reviews are considered to provide the highest level of evidence.

**META-ANALYSIS**

A systematic review can be concluded in a qualitative way by discussing, comparing and tabulating the results of the various studies, or by statistically analysing the results from independent studies: therefore conducting a meta-analysis. Meta-analysis has been defined by Glass as “the statistical analysis of a large collection of analysis results from individual studies for the purpose of integrating the findings”. By combining individual studies it is possible to provide a single and more precise estimate of the treatment effects. However, the quantitative synthesis of results from a series of studies is meaningful only if these studies have been identified and collected in a proper and systematic way. Thus, the reason why the systematic review always precedes the meta-analysis and the two methodologies are commonly used together. Ideally, the combination of individual study results to get a single summary estimate is appropriate when the selected studies are targeted to a common goal, have similar clinical populations, and share the same study design. When the studies are thought to be too different (statistically or clinically), some researchers prefer not to calculate summary estimates. Reasons for not presenting the summary estimates are usually related to study heterogeneity aspects such as clinical diversity (e.g. different metrics or outcomes, participant characteristics, different settings, etc.), methodological diversity (different study designs) and statistical heterogeneity. Some methods, however, are available for dealing with these problems in order to combine the study results. Nevertheless, the source of heterogeneity should be always explored using, for example, sensitivity analyses. In this analysis the primary studies are classified in different groups based on methodological and/or clinical characteristics and subsequently compared. Even

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after this subgroup analysis the studies included in the groups may still be statistically heterogeneous and therefore the calculation of a single estimate may be questionable.\textsuperscript{11,19} Statistically heterogeneity can be calculated with different tests but the most popular are the Cochran’s Q\textsuperscript{23} and I\textsuperscript{2}.\textsuperscript{21} Although the latter is thought to be more powerful, it has been shown that their performance is similar\textsuperscript{24} and these tests are generally weak (low power). Therefore, their confidence intervals should always be presented in meta-analyses and taken into consideration when interpreting heterogeneity. Although heterogeneity can be seen as a “statistical” problem, it is also an opportunity for obtaining important clinical information about the influences of specific clinical differences.\textsuperscript{11} Sometimes, the goal of a meta-analysis is to explore the source of diversity among studies.\textsuperscript{11} In this situation the inclusion criteria are purposely allowed to be broader.

Meta-analyses of observational studies

Although meta-analyses usually combine results from RCTs, meta-analyses of epidemiological studies (case-control, cross-sectional or cohort studies) are increasing in the literature, and therefore, guidelines for conducting this type of meta-analysis have been proposed (e.g. Meta-analysis Of Observational Studies in Epidemiology, MOOSE\textsuperscript{25}). Although the highest level of evidence study design is the RCT, observational studies are used in situations where RCTs are not possible such as when investigating the potential causes of a rare disease or the prevalence of a condition and other etiological hypotheses.\textsuperscript{3,4,11} The two designs, however, usually address different research questions (e.g. efficacy versus effectiveness) and therefore the inclusion of both RCTs and observational studies in meta-analyses would not be appropriate.\textsuperscript{11,15} Major problems of observational studies are the lack of a control group, the difficulty controlling for confounding variables, and the high risk of bias.\textsuperscript{26} Nevertheless, observational studies and therefore the meta-analyses of observational studies can be useful and are an important step in examining the effectiveness of treatments in healthcare.\textsuperscript{3,4,11} For the meta-analyses of observational studies, sensitivity analyses for exploring the source of heterogeneity is often the main aim. To note, meta-analyses themselves can be considered “observational studies of the evidence”\textsuperscript{11} and, as a consequence, they may be influenced by known and unknown confounders similarly to primary type observational studies.

Meta-analyses based on individual patient data

While “traditional” meta-analyses combine aggregate data (average of the study participants such as mean treatment effects, mean age, etc.) for calculating a summary estimate, it is possible (if data are available) to perform meta-analyses using the individual participant data on which the aggregate data are derived.\textsuperscript{27-29} Meta-analyses based on individual participant data are increasing.\textsuperscript{21} This kind of meta-analysis is considered the most comprehensive and has been regarded as the gold standard for systematic reviews.\textsuperscript{29,30} Of course, it is not possible to simply pool together the participants of various studies as if they come from a large, single trial. The analysis must be stratified by study so that the clustering of patients within the studies is retained for preserving the effects of the randomization used in the primary investigations and avoiding artifacts such as the Simpson’s paradox, which is a change of direction of the associations.\textsuperscript{11,15,20,29} There are several potential advantages of this kind of meta-analysis such as consistent data checking, consistent use of inclusion and exclusion criteria, better methods for dealing with missing data, the possibility of performing the same statistical analyses across studies, and a better examination of the effects of participant-level covariates.\textsuperscript{15,31,32} Unfortunately, meta-analyses on individual patient data are often difficult to conduct, time consuming, and it is often not easy to obtain the original data needed for performance of a such an analysis.

Cumulative and Bayesian meta-analyses

Another form of meta-analysis is the so-called “cumulative meta-analysis”. Cumulative meta-analyses recognize the cumulative nature of scientific evidence and knowledge.\textsuperscript{11} In cumulative meta-analysis a new relevant study on a given topic is added whenever it becomes available. Therefore, a cumulative meta-analysis shows the pattern of evidence over time and can identify the point when a treatment becomes clinically significant.\textsuperscript{11,15,33} Cumulative meta-analyses are not updated meta-analyses since there is not a single pooling but the results are summarized as each new study is added.\textsuperscript{33} As a consequence, in the
forest plot, commonly used for displaying the effect estimates, the horizontal lines represent the treatment effect estimates as each study is added and not the results of the single studies. The cumulative meta-analysis should be interpreted within the Bayesian framework even if they differ from the “pure” Bayesian approach for meta-analysis.

The Bayesian approach differs from the classical, or frequentist methods to meta-analysis in that data and model parameters are considered to be random quantities and probability is interpreted as an uncertainty rather than a frequency. Compared to the frequentist methods, the Bayesian approach incorporates prior distributions, that can be specified based on a priori beliefs (being unknown random quantities), and the evidence coming from the study is described as a likelihood function. The combination of prior distribution and likelihood function gives the posterior probability density function. The uncertainty around the posterior effect estimate is defined as a credibility interval, which is the equivalent of the confidence interval in the frequentist approach. Although Bayesian meta-analyses are increasing, they are still less common than traditional (frequentist) meta-analyses.

**Conducting a systematic review and meta-analysis**

As aforementioned, a systematic review must follow well-defined and established methods. One reference source of practical guidelines for properly applying methodological principles when conducting systematic reviews and meta-analyses is the Cochrane Handbook for Systematic Reviews of Interventions that is available for free online. However other guidelines and textbooks on systematic reviews and meta-analysis are available. Similarly, authors of reviews should report the results in a transparent and complete way and for this reason an international group of experts developed and published the QUOROM (Quality Of Reporting Of Meta-analyses) and recently the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines addressing the reporting of systematic reviews and meta-analyses of studies which evaluate healthcare interventions.

In this section the authors briefly present the principal steps necessary for conducting a systematic review and meta-analysis, derived from available reference guidelines and textbooks in which all the contents (and much more) of the following section can be found. A summary of the steps is presented in Figure 1. As with any research, the methods are similar to any other study and start with a careful development of the review protocol, which includes the definition of the research question, the collection and analysis of data, and the interpretation of the results. The protocol defines the methods that will be used in the review and should be set out before starting the review in order to avoid bias, and in case of deviation this should be reported and justified in the manuscript.

**Step 1. Defining the review question and eligibility criteria**

The authors should start by formulating a precise research question, which means they should clearly report the objectives of the review and what question they would like to address. If necessary, a broad research question may be divided into more specific questions. According to the PICOS framework, the question should define the Population(s), Intervention(s), Comparator(s), Outcome(s) and...
Study design(s). This information will also provide the rationale for the inclusion and exclusion criteria for which a background section explaining the context and the key conceptual issues may be also needed. When using terms that may have different interpretations, operational definitions should be provided. An example may be the term “neuromuscular control” which can be interpreted in different ways by different researchers and practitioners. Furthermore, the inclusion criteria should be precise enough to allow the selection of all the studies relevant for answering the research question. In theory, only the best evidence available should be used for the systematic reviews. Unfortunately, the use of an appropriate design (e.g. RCT) does not ensure the study was well-conducted. However, the use of cut-offs in quality scores as inclusion criteria is not appropriate given their subjective nature, and a sensitivity analysis comparing all available studies based on some methodological key characteristics is preferable.

Step 2. Searching for studies
The search strategy must be clearly stated and should allow the identification of all the relevant studies. The search strategy is usually based on the PICOS elements and can be conducted using electronic databases, reading the reference lists of relevant studies, hand-searching journals and conference proceedings, contacting authors, experts in the field and manufacturers, for example.

Currently, it is possible to easily search the literature using electronic databases. However, the use of only one database does not ensure that all the relevant studies will be found and various databases should be searched. The Physiotherapy Evidence Database (PEDro: http://www.pedro.org.au) provides free access to RCTs (about 18,000) and systematic reviews (almost 4000) on musculoskeletal and orthopaedic physiotherapy (sports being represented by more than 60%). Other available electronic databases are MEDLINE (through PubMed), EMBASE, SCOPUS, CINAHL, Web of Science of the Thomson Reuters and The Cochrane Controlled Trials Register. The necessity of using different databases is justified by the fact that, for example, 1800 journals indexed in MEDLINE are not indexed in EMBASE, and vice versa.

The creation and selection of appropriate keywords and search term lists is important to find the relevant literature, ensuring that the search will be highly sensitive without compromising precision. Therefore, the development of the search strategy is not easy and should be developed carefully taking into consideration the differences between databases and search interfaces. Although Boolean searching (e.g. AND, OR, NOT) and proximity operators (e.g. NEAR, NEXT) are usually available, every database interface has its own search syntax (e.g. different truncation and wildcards) and a different thesaurus for indexing (e.g. MeSH for MEDLINE and EMTREE for EMBASE). Filters already developed for specific topics are also available. For example, PEDro has filters included in search strategies (called SDIs) that are used regularly and automatically in some of the above mentioned databases for retrieving guidelines, RCTs, and systematic reviews.

After performing the literature search using electronic databases, however, other search strategies should be adopted such as browsing the reference lists of primary and secondary literature and hand searching journals not indexed. Internet sources such as specialized websites can be also used for retrieving grey literature (e.g. unpublished papers, reports, conference proceedings, thesis or any other publications produced by governments, institutions, associations, universities, etc.). Attempts may be also performed for finding, if any, unpublished studies in order to reduce the risk of publication bias (trend to publish positive results or results going in the same direction). Similarly, the selection of only English-language studies may exacerbate the bias, since authors may tend to publish more positive findings in international journals and more negative results in local journals. Unpublished and non-English studies generally have lower quality and their inclusion may also introduce a bias. There is no rule for deciding whether to include or not include unpublished or exclusively English-language studies. The authors are usually invited to think about the influence of these decisions on the findings and/or explore the effects of their inclusion with a sensitivity analysis.

Step 3. Selecting the studies
The selection of the studies should be conducted by more than one reviewer as this process is quite
subjective (the agreement, using kappa statistic, between reviewers should be reported together with the reasons for disagreements). Before selecting the studies, the results of the different searches are merged using reference management software and duplicates deleted. After an initial screening of titles and abstracts where the obviously irrelevant studies are removed, the full papers of potentially relevant studies should be retrieved and are selected based on the previously defined inclusion and exclusion criteria. In case of disagreements, a consensus should be reached by discussion or with the help of a third reviewer. Direct contact with the author(s) of the study may also help in clarifying a decision.

An important phase at this step is the assessment of quality. The use of quality scores for weighting the study entered in the meta-analysis is not recommended, as it is not recommended to include in a meta-analysis only studies above a cut-off quality score. However, the quality criteria of the studies must be considered when interpreting the results of a meta-analysis. This can be done qualitatively or quantitatively through subgroup and sensitivity analyses based on important methodological aspects, which can be assessed using checklists that are preferable over quality scores. If quality scores would like to be used for weighting, alternative statistical techniques have been proposed. e.g. The assessment of quality should be performed by two independent observers. The Cochrane handbook, however, makes a distinction between study quality and risk of bias (related for example to the method used to generate random allocation, concealment, blindness, etc.), focusing more on the latter. As for quality assessment, the risk of bias should be taken into consideration when interpreting the findings of the meta-analysis. The quality of a study is generally assessed based on the information reported in the studies thus linking the quality of reporting to the quality of the research itself, which is not necessarily true. Furthermore, a study conducted at the highest possible standard may still have high risk of bias. In both cases, however, it is important that the authors of primary studies appropriately report the results and for this reason guidelines have been created for improving the quality of reporting such as the CONSORT (Consolidated Standards of Reporting Trials) and the STROBE (Strengthening the Reporting

Step 4. Data extraction
Data extraction must be accurate and unbiased and therefore, to reduce possible errors, it should be performed by at least two researchers. Standardized data extraction forms should be created, tested, and if necessary modified before implementation. The extraction forms should be designed taking into consideration the research question and the planned analyses. Information extracted can include general information (author, title, type of publication, country of origin, etc.), study characteristics (e.g. aims of the study, design, randomization techniques, etc.), participant characteristics (e.g. age, gender, etc.), intervention and setting, outcome data and results (e.g. statistical techniques, measurement tool, number of follow up, number of participants enrolled, allocated, and included in the analysis, results of the study such as odds ratio, risk ratio, mean difference and confidence intervals, etc.). Disagreements should be noted and resolved by discussing and reaching a consensus. If needed, a third researcher can be involved to resolve the disagreement.

Step 5. Analysis and presentation of the results (data synthesis)
Once the data are extracted, they are combined, analyzed, and presented. This data synthesis can be done quantitatively using statistical techniques (meta-analysis), or qualitatively using a narrative approach when pooling is not believed to be appropriate. Irrespective of the approach (quantitative or qualitative), the synthesis should start with a descriptive summary (in tabular form) of the included studies. This table usually includes details on study type, interventions, sample sizes, participant characteristics, outcomes, for example. The quality assessment or the risk of bias should also be reported. For narrative reviews a comprehensive synthesis framework (Figure 2) has been proposed.

Standardization of outcomes
To allow comparison between studies the results of the studies should be expressed in a standardized format such as effect sizes. The appropriate effect size for standardizing the outcomes should be
similar between studies so that they can be compared and it can be calculated from the data available in the original articles. Furthermore, it should be interpretable. When the outcomes of the primary studies are reported as means and standard deviations, the effect size can be the raw (unstandardized) difference in means (D), the standardized difference in means (d or g) or the response ratio (R). If the results are reported in the studies as binary outcomes the effect sizes can be the risk ratio (RR), the odds ratio (OR) or the risk difference (RD).15

**Statistical analysis**

When a quantitative approach is chosen, meta-analytical techniques are used. Textbooks and courses are available for learning statistical meta-analytical techniques. Once a summary statistic is calculated for each study, a “pooled” effect estimate of the interventions is determined as the weighting average of individual study estimates, so that the larger studies have more “weight” than the small studies. This is necessary because small studies are more affected by the role of chance.11,15 The two main statistical models used for combining the results are the “fixed-effect” and the “random-effects” model. Under the fixed effect model, it is assumed that the variability between studies is only due to random variation because there is only one true (common) effect. In other words, it is assumed that the group of studies give an estimate of the same treatment effect and therefore the effects are part of the same distribution. A common method for weighting each study is the inverse-variance method, where the weight is given by the inverse of variance of each estimate. Therefore, the two essential data required for this calculation are the estimate of the effect with its standard error. On the other hand, the “random-effects” model assumes a different underlying effect for each study (the true effect varies from study to study). Therefore the study weight will take into account two sources of error: the between- and within-studies variance. As in the fixed-effect model, the weight is calculated using the inverse-variance method, but in random-effects model the study specific standard errors are adjusted incorporating both within and between-studies variance. For this reason, the confidence intervals obtained with random-effect models are usually wider. In theory, the fixed-effect model can be applied when the studies are heterogeneous while the random-effects model can be applied when the results are not heterogeneous. However, the statistical tests for examining heterogeneity lack power and, as aforementioned, the heterogeneity should be carefully scrutinized (e.g. interpreting the confidence intervals) before taking a decision. Sometimes, both fixed- and random-effects models are used for examining the robustness of the analysis. Once the analyses are completed, results should be presented as point estimates with the corresponding confidence intervals and exact p-values.

Other than the calculations of the individual studies and summary estimates, other analyses are necessary. As mentioned various time, the exploration of possible source of heterogeneity is important and can be performed using sensitivity, subgroup, or regression analyses. Using meta-regressions is also possible to examine the effects of differences in study characteristics on the treatment effect estimate. When using meta-regression, the larger studies have more influence than smaller studies; and regarding other analyses, recall that the limitations should be taken into account before deciding to use it and when interpreting the results.

**Graphic display**

The results of each trial are commonly displayed with their corresponding confidence intervals in the so-called “forest plot” (Figure 3). In the forest plot the study is represented by a square and a horizontal line indicating the confidence interval, where the
dimension of the square reflects the weight of each study. A solid vertical line usually corresponds to no effect of treatment. The summary point estimate is usually represented with a diamond at the bottom of the graph with the horizontal extremities indicating the confidence interval. This graphic solution gives an immediate overview of the results.

An alternated graphic solution called a funnel plot can be used for investigating the effects of small studies and for identifying publication bias (Figure 4). The funnel plot is a scatter-plot of the effect estimates of individual studies against measures of study size and precision (commonly, the standard error, but the use of sample size is still common). If there is no publication bias the funnel plot will be symmetrical (Figure 4B). However, the funnel plot examination is subjective, based upon visual inspection, and therefore can be unreliable. In addition, other causes may influence the symmetry of the funnel plot such as the measures used for estimating the effects and precision, and differences between small and large studies. Therefore, its use and interpretation should be done with caution.

Step 6. Interpretation of the results

The final part of the process pertains to the interpretation of the results. When interpreting or commenting on the findings, the limitations should be discussed and taken into account, such as the overall risk of bias and the specific biases of the studies included in the systematic review, and the strength of the evidence. Furthermore, the interpretation should be performed based not solely using P-values, but rather on the uncertainty and the clinical/practical importance. Ideally, the interpretation should help the clinician in understanding how to apply the findings in practice, provide recommendations or implications for policies, and offer directions for further research.

Figure 3. Example of a forest plot: the squares represent the effect estimate of the individual studies and the horizontal lines indicate the confidence interval; the dimension of the square reflects the weight of each study. The diamond represents the summary point estimate is usually represented with a diamond at the bottom of the graph with the horizontal extremities indicating the confidence interval. In the example as standardized outcome measure the authors used d.

Figure 4. Example of symmetric (A) and asymmetric (B) funnel plots.
CONCLUSIONS

Systematic reviews have to meet high methodological standards, and their results should be translated into clinically relevant information. These studies offer a valuable and useful summary of the current scientific evidence on a specific topic and can be used for developing evidence-based guidelines. However, it is important that practitioners are able to understand the basic principles behind the reviews and are hence able to appreciate their methodological quality before using them as a source of knowledge. Furthermore, there are no RCTs, systematic reviews, or meta-analyses that address all aspects of the wide variety of clinical situations. A typical example in sports physiotherapy is that most available studies deal with recreational athletes, while an individual clinician may work with high-profile or elite athletes in the clinic. Therefore, when applying the results of a systematic review to clinical situations and individual patients, there are various aspects one should consider such as the applicability of the findings to the individual patient, the feasibility in a particular setting, the benefit-risk ratio, and the patient’s values and preferences. As reported in the definition, evidence-based medicine is the integration of both research evidence and clinical expertise. As such, the experience of the sports PT should help in contextualizing and applying the findings of a systematic review or meta-analysis, and adjusting the effects to the individual patient. As an example, an elite athlete is often more motivated and compliant in rehabilitation, and may have a better outcome than average with the given physical therapy or training interventions (when compared to a recreational athlete). Therefore, it is essential to merge the available evidence with the clinical evaluation and the patient’s wishes (and consequent treatment planning) in order to engage an evidence-based management of the patient or athlete.

REFERENCES


ABSTRACT

In the design of scientific studies it is essential to decide on which scientific questions one aims to answer, just as it is important to decide on the correct statistical methods to use to answer these questions. The correct use of statistical methods is crucial in all aspects of research to quantify relationships in data. Despite an increased focus on statistical content and complexity of biomedical research these topics remain difficult for most researchers. Statistical methods enable researchers to condense large spreadsheets with data into means, proportions, and difference between means, risk differences, and other quantities that convey information. One of the goals in biomedical research is to develop parsimonious models - meaning as simple as possible. This approach is valid if the subsequent research report (the article) is written independent of whether the results are “statistically significant” or not. In the present paper we outline the considerations and suggestions on how to build a trial protocol, with an emphasis on having a rigorous protocol stage, always leading to a full article manuscript, independent of statistical findings. We conclude that authors, who find (rigorous) protocol writing too troublesome, will realize that they have already written the first half of the final paper if they follow these recommendations; authors simply need to change the protocols future tense into past tense. Thus, the aim of this clinical commentary is to describe and explain the statistical principles for trial protocols in terms of design, analysis, and reporting of findings.

Key words: analysis, research design, statistics

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INTRODUCTION

Generalized linear models, sequential analysis, time series, survival analysis, design of experiments, residuals and diagnostics, likelihood inference and statistical approximation – are all topics that might cause confusion and distract the consumer of a research paper, rather than help to clarify the objective of a biomedical research project. Despite the fact that the statistical content and complexity of biomedical research has increased steadily over recent decades, with reports of clinical trials containing a wealth of data comparing treatments, there is still a need to educate researchers in order to allow for “parsimonious statistical thinking”. Researchers, without a solid knowledge of clinical epidemiology and/or biostatistics, are often increasing the complexity of their model in their eagerness to explain “everything”, assuming that a statistician will “show up later” and “sort the whole thing out”. One of the goals in biomedical research is to develop parsimonious models to allow the testing of a hypothesis to be as simple as possible. The idea of parsimony, is here used synonymous with “Occam’s razor”, and states that when “everything else is equal, simple models are to be preferred over complex models”.

Applied statistics should not focus too much on distributions or probabilities, but rather focus on the ‘a priori’ approach to “telling the good story”; that is, focus – a priori - on how to present the project when the data collection has been finalized, and analyzed. When designing a research study it is important to decide on the statistical methods that will apply before starting the data collection. Researchers, who cannot disclose the anticipated outline of their paper a priori, are most likely introducing bias into the biomedical literature. The end user of biomedical research, might infer erroneous conclusions (after synthesis) from the totality of the available evidence, as a consequence of the complete results of all conducted studies on a question of interest not being available in the public domain, thereby introducing publication and/or selective outcome reporting bias. Biostatistics is the use of numbers to quantify relationships in data, whether empirical or causal, and thereby answer the scientific questions raised in the original protocol. This approach is valid if the subsequent research article is written independent of whether the results are “statistically significant” or not. It is very unfortunate, that the process of running the main analyses requires only little time, whereas preparing a manuscript requires considerable effort, and thus frequently leads to situations where the scientists ponder (post hoc) whether it is worth manuscript preparation. They weigh the perceived importance and priority of the question, the statistical significance of any (quickly obtained) results, and other evidence circulating at the time.

Statistical methods should enable the researcher to reduce a large spreadsheet with collected variables (including outcome measures and design variables) into means, proportions, and difference between means, risk differences, and other quantities that convey information. In principle this kind of statistics are called descriptive statistics, enabling the reader to do most of the subsequent statistical tests by hand while reading the paper a phenomenon often referred to as transparent reporting of statistical data. The use of explicit numerical information will be enhanced if authors remain focused on the original ‘Statistical Analysis Plan’ (SAP) as outlined in the pre-specified protocol of the study.

The authors objective for this manuscript is to provide suggestions and considerations on what to prepare before initiating the study (collecting data), with an emphasis on having a rigorous protocol stage that leads to a full article manuscript, independent of statistical findings.

CONCEPTUALIZING COHORT STUDIES AS IF THEY WERE RCTS

Valid evidence on the benefits and risks of healthcare interventions is essential in decision-making. Randomized controlled trials (RCTs) are considered the ultimate method for providing evidence on efficacy. Frequently, however, the RCTs are criticized for focusing on highly selected populations and outcomes. Therefore cohort studies can be thought of as natural experiments in which outcomes are measured in real world rather than in experimental settings. Whether the statistical design is based on observational or randomized data, the reporting of both types of studies is often of insufficient quality, and poor reporting hampers the assessment of the strengths and weaknesses of a study and the generalizability of its results. Because of this, a group of scientists and editors devel-
oped the CONSORT (Consolidated Standards of Reporting Trials) statement to improve the quality of reporting of RCTs, and the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statement with recommendations on how to improve the quality when reporting from observational studies. The STROBE statement covers cohort, cross-sectional, and case-control designs. Often the ideas and intentions of cohort studies are similar to RCTs in that they compare outcomes in groups that did and did not receive an intervention (Exposed vs. Unexposed, respectively). The main difference is that allocation of individuals is not by chance (random) in the observational studies. Rigorous RCTs eliminate selection bias, balancing both known and unknown prognostic factors, in the assignment of treatments. If done inadequately, treatment comparisons may be prejudiced, whether consciously or not, by selection of participants of a particular kind to receive a particular treatment.

Unlike RCTs, cohort studies are always vulnerable to selection bias. In cohort studies, factors that determined whether a person received the intervention could result in the groups differing in factors related to the outcome, either because people were preferentially selected to receive one treatment or because of choices that they made. These baseline differences in prognosis could “confound the assessment of the effect” of the intervention. Confounding means “confusion of effects” as a consequence, authors could naively consider a cohort study comparing individuals exposed to those individuals without exposure as a quasi-randomized trial when building the SAP. This should then be followed by a clear description about which (potential) confounding factors they would adjust for in the final and fully adjusted model. Information on the distribution of potential confounders in the intervention and comparison groups is usually—and preferably—provided in the first table of a manuscript reporting from a cohort study.

Confounding is a problem only if some baseline characteristics are unevenly distributed between the intervention and comparison groups. When reporting such a study, where you compare groups at baseline (Exposed vs. Unexposed or Intervention vs. Placebo), it is tempting to report a p-value, despite the fact that the test probably either has a low statistical power, or are impossible to interpret as it is the case for RCTs.

In assessing cohort studies, it is important to identify potential confounders and to examine their distribution in the exposed and control group. Although unknown confounders are always difficult to deal with in cohort studies, a systematic approach can be used to identify known and potential confounders. Typical features could be demographic (e.g., age and sex), medical (e.g., concomitant disease/conditions), previous or current exposure to drugs, and social and behavioral factors (e.g., habits, exercise and diet). When comparing different potential confounding factors between groups at baseline, as previously suggested by Mamdani et al, the authors recommend alternative to traditional significance testing, authors use standardized differences or effect sizes to examine ‘between group differences’ in patient characteristics. The most important thing in regard to detecting bias due to confounding (assessed at baseline), is that it cannot be judged solely by statistical significance; usually the impact of a potential confounder is judged pragmatically on whether the adjustment for the “confounding variable” changes the estimate of association. The authors of this manuscript recommend that authors of cohort studies to apply a “three-stage reporting framework”: Model #1 report the crude analysis (without any adjustments for confounders); Model #2 report the semi-adjusted analysis (including all the a priori defined covariates that are likely to be confounding factors); Model #3 Fully adjusted model (including all the protocolized covariates as in model #2 plus those of potential interest according to baseline table discrepancies across groups).

METHODS SECTIONS IN PROTOCOL

In the following sections the authors will elaborate on important aspects of designing and reporting a two-group comparison whether it is a randomized trial, or a cohort study. For those with a particular interest in cohort studies we will encourage them to scrutinize the highly informative ‘Reader’s guide to critical appraisal of cohort studies’ published in 2005 in British Medical Journal. Likewise, we remind authors of observational studies to consult the STROBE statement on how to report cohort, cross-sectional, and case-control studies in biomedical journals. As a consequence of trying to exclude the technicalities involved in cohort studies, we will in
the latter part focus on what to consider when preparing a report for a controlled trial. Two documents are highly endorsed: The CONSORT statement (used by IJSPT), as well as the international guideline on statistical methodology (E9) to the collection of ‘International Conference on Harmonisation’ (ICH E9) on statistical principles for clinical trials.11

**Trial protocol**

Once a “clinical question” has been raised, the first step in the conception of a trial is to develop a trial protocol. Protocol development has evolved over the last decades. Writing a protocol for a trial is both an intellectual, rigorous, and creative task, which is usually done by researchers and experts in various areas of research including medical, scientific, statistical, ethical, administrative fields, and maybe even regulatory bodies. The protocol serves as the foundation for study conduct and reporting. Full knowledge of a trial protocol allows an appropriate ethical assessment before trial inception, and the proper critical appraisal of the results after trial completion. The SPIRIT initiative (Standard Protocol Items: Recommendations for Interventional Trials) are currently preparing a statement that will most likely include a final 33-item checklist that will apply in the future when researchers design and register their trials. This SPIRIT checklist will support the CONSORT statement, and explicitly ask for details about important features of the pre-specified protocol.

It is recommended that the protocol include at least the following domains: Administrative information; Introduction – including background, rationale, and objective(s); Methods (#1): Participants, interventions, and outcomes; Methods (#2): Assignment of interventions – including sequence generation, concealed allocation, etc.; Methods (#3): Sample size, data collection process, management, and statistical analysis; Methods (#4): Data monitoring; Results: Propose a preliminary outline of the study report; Ethics and dissemination; and finally appendices to all of the above. Independent of these proposed protocol items, we strongly encourage trialists to follow the CONSORT checklist when designing the study.

Before launching a trial, it is important that the researcher considers whether the hypotheses are stated in advance and planned to be evaluated to confirm the hypotheses (i.e., a confirmatory trial), or whether the researchers want to explore different clear and precise objectives (i.e., exploratory trial). Unlike confirmatory trials, exploratory studies may not always lead to simple tests of predefined hypotheses. With this in mind it seems that exploratory studies, as they are more flexible, may be the “better strategic choice”; however, be aware that an exploratory study can never confirm whether e.g. a physical therapy intervention is effective or not. Decision makers would likely argue, that a given intervention that shows promising results in exploratory studies would need at least one (phase-3-like) confirmatory ‘landmark study’.

**Trial design**

The design of the trial should be described, for example, as parallel group, cluster randomized, crossover, factorial, superiority, equivalence or non-inferiority design, or some other combination of these designs.6 The most common RCT design is the parallel group trial, in which participants are randomized to one of two (or more) interventions, with each arm being allocated a different treatment. The assumptions for these trials are less complex than for most other trial designs.

In a cross-over design, participants are randomly allocated to different sequences of treatments, and thereby act as his or her own control for treatment comparisons. In the simplest 2×2 cross-over design each participant receives each of two treatments in a randomized order in two successive periods, usually separated by a washout period. Cross-over designs have a number of caveats that can invalidate their results. The major concern is “carryover effects” where the first treatment given is able to influence the “response” in the subsequent treatment. The statistical consequence might be that the effect of unequal carryover will be to bias direct treatment comparisons.

In a factorial design, participants are assigned to more than one treatment-comparison group, enabling two or more treatments being evaluated simultaneously. The simplest example is the 2×2 factorial design where participants are randomly allocated to one of four possible combinations of two treatments (e.g. A and B). This allows the statistical model to statistically
conclude from A alone; B alone; both A & B; neither A nor B. Usually the statistical focus in studies with factorial design will be on examining the interaction between A and B.

Participants
For each of the following paragraph headings, that are all directly associated with the protocol the authors remind researchers to report what they anticipate will characterize the participants rather than waiting for the final data. This includes explicit eligibility criteria (i.e., both inclusion and exclusion criteria) for participants and the settings where the data will be collected. RCTs address an issue relevant to a particular population or group with the condition of interest. Participant eligibility criteria may relate to demographics, clinical diagnosis, and comorbidity conditions. A clear description of the trial participants and setting in which they will be studied is needed to allow future readers to assess the external validity (generalizability) of the trial and determine its applicability to their own setting.

Interventions and blinding
Detailed information on the interventions intended for each group including the essential features of the experimental and comparison interventions (e.g., control group) should be described. Authors should report details about the interventions, e.g., dose, route of administration, duration of administration, surgical procedure, or manufacturer of inserted device. When describing the interventions it is very important to report whether or not participants care givers, and those assessing the outcomes will be blinded to group assignment. Blinding refers to the practice of keeping the trial participants, care providers, data collectors, and sometimes those analyzing the data, unaware of which intervention is being administered to which participant, to reduce the risk of bias. Authors should avoid using terms such as “single” or “double” blind as such terms are not precise enough.

Outcomes
It is important to clearly define what will be the primary outcome for the trial, as well as what are the secondary outcomes. The primary outcome (‘primary variable’, ‘target variable’, ‘primary endpoint’)

should be the variable capable of providing the most clinically relevant and convincing evidence directly related to the primary objective of the trial and is usually the one variable used for the sample size calculation. Most trials have several outcomes, some of which are deemed more important than others. Such rankings are typically reported as primary and secondary outcomes. Ideally there should only be one primary outcome. Authors should explicitly state the primary outcome for the trial and when it will be assessed (e.g., the time frame over which it is measured).

Secondary outcomes are either supportive measurements related to the primary objective or measurements of effects related to the secondary objectives. Their definition in the protocol is also important, as well as an explanation of their relative importance and roles in interpretation of trial results. Generally, the number of secondary outcome variables should be limited and should be related to the limited number of questions attempted answered in the trial.

Sample size
The number of participants in a trial should always be large enough to provide a reliable answer to the research questions addressed. The number of participants randomized to each intervention group is an essential element of the results of a trial. This number defines the sample size, and readers of the published article can use it to assess whether all randomized participants were included in the study and subsequent data analysis (referred to as the “Intention To Treat” (ITT) population).

Investigators calculate sample sizes before the start of their trial and adequately describe what went into the calculation in details in their protocol as well as their published report. In these a priori calculations, determining the effect size to detect—e.g., difference between means (MD = M₁ - M₂), or risk difference calculated from the proportions who respond (RD = p₁ - p₂) — reflects inherently subjective clinical judgments. The term treatment effect or effect size generally means – for efficacy outcomes - the net benefit, of applying intervention 'I' compared to intervention 'C'. Typically the type of outcome data used for sample size estimation is either 'binary data' (where the participant can have a response yes/no),
or it can be estimated from ‘continuous data’ (where the variable is typically guestimated from an expected mean value and a corresponding standard deviation). The authors need to decide a priori what kind of clinical net benefit (difference between groups) they would expect from the intervention, with focus on clinical relevance.

When determining the appropriate sample size, the following items should be considered and specified: (#1) a primary outcome (i.e., the “name” and whether it is binary or continuous by nature); (#2) the test statistic, (#3) the null hypothesis, and the alternative hypothesis (i.e., the reason for the study); (#4) the probability of erroneously rejecting the null hypothesis (the type I error, i.e., the statistical p-value); and (#5) the probability or erroneously failing to reject the null hypothesis (the type II error, i.e., 1 – the type II error is referred to as the statistical power of the study). When determining the sample size for a trial it is also important to consider the protocol approach to dealing with treatment withdrawals and protocol violations.

In an excellent tutorial paper, published in the Lancet, Schulz and Grimes argue that the subjective judgments needed from the authors (i.e., content experts) to be able to estimate the sample size - or maybe the statistical power if the number of participants is already determined – is necessary for the trial to be trusted.15 Realizing that these judgments greatly affect sample size calculations, Schulz and Grimes question the branding of trials as unethical on the basis of an imprecise sample size calculation process. They claim, that, some shift of emphasis from a fixation on sample size to a focus on methodological quality would yield more trials with less bias;16 unbiased trials with imprecise results trump no results at all.15

**Randomization**

Investigators should make sure to describe how participants will be randomized and allocated to the different interventions. It is important to conceal the allocation sequence from those assigning participants to the intervention groups. Allocation concealment prevents investigators from influencing which participants are assigned to a given intervention group (i.e., selection bias). Evidence shows that reports of trials reporting inadequate allocation concealment are associated with exaggerated treatment effects. Authors should clearly describe in the protocol the method for assigning participants to interventions. Examples of approaches used to ensure adequate concealment include: centralized (e.g., allocation by a central office) or pharmacy-controlled randomization; sequentially numbered identical containers that are administered serially to participants; on-site computer system combined with allocations kept in a locked, unreadable computer file that investigators can access only after the characteristics of an enrolled participant are entered; and sequentially numbered, opaque sealed envelopes.6

**Statistical methods**

Medical research is carried out on selected individuals, although the selection criteria are not always clear. As indicated above, each of the mentioned paragraphs could – if manipulated with – lead to biased results and maybe even biased conclusions. In a statistical analysis plan, emphasis should be on which analyses, comparisons, and statistical tests have been planned - given the objective of the study. The statistical methods section should include all the principal features of the proposed confirmatory analysis of the primary variable(s) and the way in which anticipated analysis problems will be handled. In the case of exploratory trials this section could describe more general principles and directions.

The set of participants whose data are to be included in the main analyses should be defined in the statistical section of the protocol. If there are any planned reasons, for excluding from analysis participants for whom data are available, these should be described. Some trials use terminology for these different scenarios (Analysis sets), such as: (#1) Full analysis set: The set of participants that is as close as possible to the ideal implied by the ITT principle. It is derived from the set of all randomized subjects by minimal and justified elimination of subjects; and, (#2) Per protocol set (valid cases, efficacy sample, evaluable participants sample): The set of data generated by the subset of participants who complied with the protocol sufficiently to ensure that these data would be likely to exhibit the effects of treatment, according to the underlying scientific model. In general
the ITT population (full analysis set) should be considered for all primary analyses. However, it is advantageous to demonstrate a lack of sensitivity of the principal trial results to alternative choices of the set of subjects analyzed.

When writing your statistical analysis plan, realize that data can be analyzed in many ways, although some of which may not be strictly appropriate in the particular situation. It is essential to specify which statistical procedure will be used for each analysis (given your objective and anticipated imaginary data set). Later in the full report (article) further clarification may be necessary in the results section, but this should never be in conflict with the analyses proposed in the protocol. When considering how elaborate such a paragraph needs to be, the principle is to describe statistical methods with enough detail to enable a knowledgeable reader with access to the original data17 to verify the reported results.

Most trial objectives result in statistical analyses yielding estimates of the treatment effect, which is a contrast between the outcomes in the comparison groups. These group contrasts should be followed by a confidence interval (usually 95% CI) for the estimated effect, which indicates a central range of uncertainty for the true treatment effect. Study findings can also be assessed in terms of their “statistical significance”. The “p-value” represents the probability that the observed data could have arisen by chance when the interventions did not truly differ. Which is why “very small” p-values (e.g., p < 0.0001) indicate that it is highly unlikely that the interventions on trial are equally good18; actual p-values (for example, p = 0.031) are strongly preferable to imprecise threshold reports such as p < 0.05.

Finally, standard methods of analysis assume that the data are “independent.” For controlled trials, this usually means that there is one observation per participant. Treating multiple observations from one participant as independent data is a serious error; such data are produced when outcomes can be measured on different parts of the body, as in dentistry or rheumatology.6,19 Data analysis should be based on counting each participant once (e.g., as a single change from baseline) or should be done by using more complex statistical procedures.20,21

**RESULTS AND OUTLINE**

When you are finally done with conducting the procedures involved in your randomized trial, it is time to celebrate. You now have a very valuable database, where all your pre-specified objectives can be explored. Remember if you - or a junior colleague you are supervising - feel that it is too troublesome to write rigorous protocols, that there is a clear advantage at this stage: you have already written the first half of your article - you simply need to change the future tense into past tense. If you worry about what a good logical outline for the results section of such a trial could look like, we recommend that you scrutinize the examples given in the CONSORT statement,6 or follow other published examples with a rigorous reporting approach.22 Usually the following format is obvious: Figure 1: Trial flow diagram; Table 1: Baseline characteristics of participants randomized; Figure 2: Graphical display of the key findings from for the primary analysis and primary outcome (means or proportions with standard errors and 95% confidence interval); Table 2: Change from baseline at endpoint, for all the variables assessed in the study, both primary and secondary (means or proportions with standard errors and 95% confidence interval).

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ABSTRACT

Successful production of a written product for submission to a peer-reviewed scientific journal requires substantial effort. Such an effort can be maximized by following a few simple suggestions when composing/creating the product for submission. By following some suggested guidelines and avoiding common errors, the process can be streamlined and success realized for even beginning/novice authors as they negotiate the publication process. The purpose of this invited commentary is to offer practical suggestions for achieving success when writing and submitting manuscripts to *The International Journal of Sports Physical Therapy* and other professional journals.

*Key words:* Journal submission, scientific writing, strategies and tips

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INTRODUCTION

“The whole of science is nothing more than a refinement of everyday thinking”
Albert Einstein

Conducting scientific and clinical research is only the beginning of the scholarship of discovery. In order for the results of research to be accessible to other professionals and have a potential effect on the greater scientific community, it must be written and published. Most clinical and scientific discovery is published in peer-reviewed journals, which are those that utilize a process by which an author’s peers, or experts in the content area, evaluate the manuscript. Following this review the manuscript is recommended for publication, revision or rejection. It is the rigor of this review process that makes scientific journals the primary source of new information that impacts clinical decision-making and practice.1,2

The task of writing a scientific paper and submitting it to a journal for publication is a time-consuming and often daunting task.3,4 Barriers to effective writing include lack of experience, poor writing habits, writing anxiety, unfamiliarity with the requirements of scholarly writing, lack of confidence in writing ability, fear of failure, and resistance to feedback.5 However, the very process of writing can be a helpful tool for promoting the process of scientific thinking,6,7 and effective writing skills allow professionals to participate in broader scientific conversations. Furthermore, peer review manuscript publication systems requiring these technical writing skills can be developed and improved with practice.8 With these reasons for acceptance or rejection in mind, it is time to review basics and general writing tips to be used when performing manuscript preparation.

“Begin with the end in mind”. When you begin writing about your research, begin with a specific target journal in mind.12 Every scientific journal should have specific lists of manuscript categories that are preferred for their readership. The IJSPT seeks to provide readership with current information to enhance the practice of sports physical therapy. Therefore the manuscript categories accepted by IJSPT include: Original research; Systematic reviews of literature; Clinical commentary and Current concept reviews; Case reports; Clinical suggestions and unique practice techniques; and Technical notes. Once a decision has been made to write a manuscript, compose an outline that complies with the requirements of the target submission journal and has each of the suggested sections. This means carefully checking the submission criteria and preparing your paper in the exact format of the journal to which sports physical therapy. Failure to publish important findings significantly diminishes the potential impact that those findings may have on clinical practice.9

BASICS OF MANUSCRIPT PREPARATION & GENERAL WRITING TIPS

To begin it might be interesting to learn why reviewers accept manuscripts! Reviewers consider the following five criteria to be the most important in decisions about whether to accept manuscripts for publication: 1) the importance, timeliness, relevance, and prevalence of the problem addressed; 2) the quality of the writing style (i.e., that it is well-written, clear, straightforward, easy to follow, and logical); 3) the study design applied (i.e., that the design was appropriate, rigorous, and comprehensive); 4) the degree to which the literature review was thoughtful, focused, and up-to-date; and 5) the use of a sufficiently large sample.10 For these statements to be true there are also reasons that reviewers reject manuscripts. The following are the top five reasons for rejecting papers: 1) inappropriate, incomplete, or insufficiently described statistics; 2) over-interpretation of results; 3) use of inappropriate, suboptimal, or insufficiently described populations or instruments; 4) small or biased samples; and 5) text that is poorly written or difficult to follow.10,11 With these reasons for acceptance or rejection in mind, it is time to review basics and general writing tips to be used when performing manuscript preparation.
you intend to submit. Be thoughtful about the distinc- tion between content (what you are reporting) and structure (where it goes in the manuscript). Poor placement of content confuses the reader (reviewer) and may cause misinterpretation of content.³,⁵

It may be helpful to follow the IMRaD format for writing scientific manuscripts. This acronym stands for the sections contained within the article: Introduction, Methods, Results, and Discussion. Each of these areas of the manuscript will be addressed in this commentary.

Many accomplished authors write their results first, followed by an introduction and discussion, in an attempt to “stay true” to their results and not stray into additional areas. Typically the last two portions to be written are the conclusion and the abstract.

The ability to accurately describe ideas, protocols/procedures, and outcomes are the pillars of scientific writing. Accurate and clear expression of your thoughts and research information should be the primary goal of scientific writing.¹² Remember that accuracy and clarity are even more important when trying to get complicated ideas across. Contain your literature review, ideas, and discussions to your topic, theme, model, review, commentary, or case. Avoid vague terminology and too much prose. Use short rather than long sentences. If jargon has to be utilized keep it to a minimum and explain the terms you do use clearly.¹³

Write with a measure of formality, using scientific language and avoiding conjunctions, slang, and discipline or regionally specific nomenclature or terms (e.g. exercise nicknames). For example, replace the term “Monster walks” with “closed-chain hip abduction with elastic resistance around the thighs”. You may later refer to the exercise as “also known as Monster walks” if you desire.

Avoid first person language and instead write using third person language. Some journals do not ascribe to this requirement, and allow first person references, however, IJSPT prefers use of third person. For example, replace “We determined that...” with “The authors determined that...”.

For novice writers, it is really helpful to seek a reading mentor that will help you pre-read your submission. Problems such as improper use of grammar, tense, and spelling are often a cause of rejection by reviewers. Despite the content of the study these easily fixed errors suggest that the authors created the manuscript with less thought leading reviewers to think that the manuscript may also potentially have erroneous findings as well. A review from a second set of trained eyes will often catch these errors missed by the original authors. If English is not your first language, the editorial staff at IJSPT suggests that you consult with someone with the relevant expertise to give you guidance on English writing conventions, verb tense, and grammar. Excellent writing in English is hard, even for those of us for whom it is our first language!

Use figures and graphics to your advantage. Consider the use of graphic/figure representation of data and important procedures or exercises. Tables should be able to stand alone and be completely understandable at a quick glance. Understanding a table should not require careful review of the manuscript! Figures dramatically enhance the graphic appeal of a scientific paper. Many formats for graphic presentation are acceptable, including graphs, charts, tables, and pictures or videos. Photographs should be clear, free of clutter or extraneous background distractions and be taken with models wearing simple clothing. Color photographs are preferred. Digital figures (Scans or existing files as well as new photographs) must be at least 300dpi. All photographs should be provided as separate files (jpeg or tif preferred) and not be embedded in the paper. Quality and clarity of figures are essential for reproduction purposes and should be considered before taking images for the manuscript.

A video of an exercise or procedure speaks a thousand words. Please consider using short video clips as descriptive additions to your paper. They will be placed on the IJSPT website and accompany your paper. The video clips must be submitted in MPEG-1, MPEG-2, Quicktime (.mov), or Audio/Video Interface (.avi) formats. Maximum cumulative length of videos is 5 minutes. Each video segment may not exceed 50 MB, and each video clip must be saved as a separate file and clearly identified. Formulate descriptive figure/video and Table/chart/graph titles and place them on a figure legend document. Carefully consider placement of, naming of, and location of figures. It makes the job of the editors much easier!
Avoid Plagiarism and inadvertent lack of citations.
Finally, use citations to your benefit. Cite frequently in order to avoid any plagiarism. The bottom line: *If it is not your original idea, give credit where credit is due.* When using direct quotations, provide not only the number of the citation, but the page where the quote was found. All citations should appear in text as a superscripted number followed by punctuation. It is the authors’ responsibility to fully ensure all references are cited in completed form, in an accurate location. Please carefully follow the instructions for citations and check that all references in your reference list are cited in the paper and that all citations in the paper appear correctly in the reference list. Please go to IJSPT submission guidelines for full information on the format for citations.

CONTENT

Abstract
Sometimes written as an afterthought, the abstract is of extreme importance as in many instances this section is what is initially previewed by readership to determine if the remainder of the article is worth reading. This is the authors opportunity to draw the reader into the study and entice them to read the rest of the article. The abstract is a summary of the article or study written in 3rd person allowing the readers to get a quick glance of what the contents of the article include. Writing an abstract is rather challenging as being brief, accurate and concise are requisite. The headings and structure for an abstract are usually provided in the instructions for authors. In some instances, the abstract may change slightly pending content revisions required during the peer review process. Therefore it often works well to complete this portion of the manuscript last. Remember the abstract should be able to stand alone and should be as succinct as possible.14

Introduction and Review of Literature
The introduction is one of the more difficult portions of the manuscript to write. Past studies are used to set the stage or provide the reader with information regarding the necessity of the represented project. For an introduction to work properly, the reader must feel that the research question is clear, concise, and worthy of study.

A competent introduction should include at least four key concepts: 1) significance of the topic, 2) the information gap in the available literature associated with the topic, 3) a literature review in support of the key questions, 4) subsequently developed purposes/objectives and hypotheses.9

When constructing a review of the literature, be attentive to “sticking” or “staying true” to your topic at hand. Don't reach or include too broad of a literature review. For example, do not include extraneous information about performance or prevention if your research does not actually address those things. The literature review of a scientific paper is not an exhaustive review of all available knowledge in a given field of study. That type of thorough review should be left to review articles or textbook chapters. Throughout the introduction (and later in the discussion!) remind yourself that a paper, existing evidence, or results of a paper cannot draw conclusions, demonstrate, describe, or make judgments, only PEOPLE (authors) can. “The evidence demonstrates that” should be stated, “Smith and Jones, demonstrated that....”

Conclude your introduction with a solid statement of your purpose(s) and your hypothesis(es), as appropriate. The purpose and objectives should clearly relate to the information gap associated with the given manuscript topic discussed earlier in the introduction section. This may seem repetitive, but it actually is helpful to ensure the reader clearly sees the evolution, importance, and critical aspects of the study at hand See Table 1 for examples of well-stated purposes.

Methods
The methods section should clearly describe the specific design of the study and provide clear and concise description of the procedures that were performed. The purpose of sufficient detail in the methods section is so that an appropriately trained person would be able to replicate your experiments.15 There should be complete transparency when describing the study. To assist in writing and manuscript preparation there are several checklists or guidelines that are available on the IJSPT website. The CONSORT guidelines can be used when developing and reporting a randomized controlled trial.16 The STARD checklist was developed for designing a diagnostic accuracy study.17 The PRISMA checklist was developed for use when performing a meta-analyses or systematic review.18 A clear methods section should contain the following information: 1)
the population and equipment used in the study, 2) how the population and equipment were prepared and what was done during the study, 3) the protocol used, 4) the outcomes and how they were measured, 5) the methods used for data analysis. Initially a brief paragraph should explain the overall procedures and study design. Within this first paragraph there is generally a description of inclusion and exclusion criteria which help the reader understand the population used. Paragraphs that follow should describe in more detail the procedures followed for the study. A clear description of how data was gathered is also helpful. For example were data gathered prospectively or retrospectively? Who if anyone was blinded, and where and when was the actual data collected?

Although it is a good idea for the authors to have justification and a rationale for their procedures, these should be saved for inclusion into the discussion section, not to be discussed in the methods section. However, occasionally studies supporting components of the methods section such as reliability of tests, or validation of outcome measures may be included in the methods section.

The final portion of the methods section will include the statistical methods used to analyze the data. This does not mean that the actual results should be discussed in the methods section, as they have an entire section of their own!

Most scientific journals support the need for all projects involving humans or animals to have up-to-date documentation of ethical approval. The methods section should include a clear statement that the researchers have obtained approval from an appropriate institutional review board.

Results, Discussion, and Conclusions
In most journals the results section is separate from the discussion section. It is important that you clearly distinguish your results from your discussion. The results section should describe the results only. The discussion section should put those results into a broader context. Report your results neutrally, as you “found them”. Again, be thoughtful about content and structure. Think carefully about where content is placed in the overall structure of your paper. It is not appropriate to bring up additional results, not discussed in the results section, in the discussion. All results must first be described/presented and then discussed. Thus, the discussion should not simply be a repeat of the results section. Carefully discuss where your information is similar or different from other published evidence and why this might be so. What was different in methods or analysis, what was similar?

### Table 1. Examples of well-stated purposes by submission type.

<table>
<thead>
<tr>
<th>Type of Submission</th>
<th>Example purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original Research</td>
<td>Therefore, the purpose of this study was to describe the volume of pitching for pitchers from multiple college teams at the Division I level.</td>
</tr>
<tr>
<td>Systematic Review of the Literature</td>
<td>Therefore, the purpose of this systematic review was to investigate the association between training characteristics and running related injuries.</td>
</tr>
<tr>
<td>Clinical Commentary/Current Concepts Report</td>
<td>The purpose of this clinical commentary is to examine the risk factors contributing to the high recurrence rate of hamstring injuries, and propose a unique rehabilitation strategy addressing these factors in order to decrease the rate of reinjury.</td>
</tr>
<tr>
<td>Case Report</td>
<td>The purpose of this case report is to describe the non-surgical management of a professional athlete with the characteristic signs and symptoms of a sports hernia.</td>
</tr>
<tr>
<td>Clinical Suggestion</td>
<td>The purpose of this clinical commentary is to review types of integumentary wounds that may occur in sport, and their acute management.</td>
</tr>
</tbody>
</table>
As previously stated, stick to your topic at hand, and do not overstretch your discussion! One of the major pitfalls in writing the discussion section is overstating the significance of your findings or making very strong statements. For example, it is better to say: “Findings of the current study support...” or “these findings suggest...” than, “Findings of the current study prove that...” or “this means that...”. Maintain a sense of humbleness, as nothing is without question in the outcomes of any type of research, in any discipline! Use words like “possibly”, “likely” or “suggests” to soften findings.

Do not discuss extraneous ideas, concepts, or information not covered by your topic/paper/commentary. Be sure to carefully address all relevant results, not just the statistically significant ones or the ones that support your hypotheses. When you must resort to speculation or opinion, be certain to state that up front using phrases such as “we therefore speculate” or “in the authors’ opinion”.

Remember, just as in the introduction and literature review, evidence or results cannot draw conclusions, just as previously stated, only people, scientists, researchers, and authors can!

Finish with a concise, 3-5 sentence conclusion paragraph. This is not just a restatement of your results, rather is comprised of some final, summative statements that reflect the flow and outcomes of the entire paper. Do not include speculative statements or additional material; however, based upon your findings a statement about potential changes in clinical practice or future research opportunities can be provided here.

**CONCLUSIONS**

Writing for publication can be a challenging yet satisfying endeavor. The ability to examine, relate, and interlink evidence, as well as to provide a peer-reviewed, disseminated product of your research labors can be rewarding. A few suggestions have been offered in this commentary that may assist the novice or the developing writer to attempt, polish, and perfect their approach to scholarly writing.

**REFERENCES**

11. Pierson DJ. The top 10 reasons why manuscripts are not accepted for publication. *Respir Care*. 2004;49:1246-1251.
INVITED COMMENTARY

AVOIDING MANUSCRIPT MISTAKES

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ABSTRACT
Writing a scientific manuscript can be a consuming, but rewarding task with a number of intrinsic and extrinsic benefits. The ability to write a scientific manuscript is typically not an emphasized component of most entry-level professional programs. The purpose of this overview is to provide authors with suggestions to improve manuscript quality and to provide mechanisms to avoid common manuscript mistakes that are often identified by journal reviewers and editors.

Key words: manuscript, scientific writing

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INTRODUCTION
Writing a scientific manuscript can be a relatively time consuming task, but publishing clinical or research findings is a primary responsibility of a scholarly clinician. Clearly, publishing benefits the profession by documenting clinical methodology, techniques and findings, but there are personal benefits as well. These include seeing your name in print, being acknowledged by other professional peers, and providing a potential for career advancement. In an academic center, career advancement is measured by promotion and tenure and often relies on publication productivity. Clinicians can also benefit from publishing, particularly in a clinical forum and that expectation is shared in other clinical disciplines, specifically nursing and medicine. Unfortunately, some individuals do not consider or pursue publication of their findings. A recent review of abstracts presented at the Combined Sections Meeting of the American Physical Therapy Association showed that less than 25% were published five years later. Although many barriers exist, the low numbers may be associated with the time commitment associated with writing, a lack confidence with writing ability, or a frustration with the peer-review process. Published manuscripts impact clinical practice and future research, thus manuscripts and ideas that are not shared with others, fail to advance clinical practice.

Most manuscripts are typically derived from ideas or questions. Clearly defined ideas or questions provide the initial framework for scientific discovery and manuscript development. Well-planned and organized research studies often have the initial components of a manuscript (introduction, methods, statistical analysis) in place with the exception of finalized results and the discussion and conclusion(s). Case studies may not have the initial manuscript components in place, but clinicians benefit from foundational knowledge of the topic area and clinical methodology that parallels the components the scientific method (construct hypothesis, test, analyze results, and draw conclusions). The use of consistent assessment methods and standardized outcomes in clinical settings provides clinicians the ability to capitalize on case study opportunities or a report of case series.

Scientific writing is not usually an emphasized component of most professional education programs. Although scientific writing requires foundational knowledge to understand the topic area, the ability to communicate those thoughts is enhanced with practice. Writing is a skill that develops with practice, not unlike the clinical skills of performing special tests or manual therapy. Writing a scientific manuscript can be simplistically thought of as a blend of storytelling and writing a clinical note. The ability to capture the interest of the reader by providing a systematic and logical flow of relevant information (storytelling) is enhanced by presenting detailed methodology and objective findings (clinical note). The purpose of this overview is to provide authors with suggestions to improve manuscript quality and to provide mechanisms to avoid common manuscript mistakes that are often identified by journal reviewers and editors. The first portion of this paper will focus on general tips for writing manuscripts and the second portion will provide section specific suggestions. A broad overview of common mistakes is presented in Table 1.

GENERAL TIPS
Consider the Reader
Authors should consider the individuals who will read their manuscript once it is published, thus it is essential to know your audience. Although most scientific works are available on-line, most clinicians use paper journals subscriptions associated with their membership fees to stay current in the literature. Some journals are targeted toward a strictly clinical population, some only consider standardized research interventions and some publish only methodological findings. For example, the International Journal of Sports Physical Therapy includes clinical commentary, case report, systematic and literature review papers, and original research that are targeted to clinically oriented individuals who treat musculoskeletal pathologies. Sports Medicine, however, only publishes invited reviews on clinically relevant topics and Physical Therapy includes research only on a pathological patient population. Knowing the guidelines, restrictions and target population for each journal is essential and will save valuable time during the submission and review process.

Writing Style
Writing a manuscript is analogous to telling a story and individual statements should flow to subsequent components or paragraphs. Following a logical sequence
with simplistic writing will help the reader better understand the author's thoughts and this method improves reader interest. The use of simple words and short relevant sentences is encouraged and authors should note that they are not writing a novel. Sentences should be complete coherent thoughts and contribute to the content within the paragraph. Paragraphs should also consist of multiple sentences, not stand-alone single sentences or fewer than 3 sentences.

When constructing paragraphs it is helpful to have strong first and last sentences, which are used to transition from the previous or subsequent paragraph or section. Careful use of headings and subheadings can improve the flow of the manuscript if a logical progression between thoughts is not possible. A good test to determine if the manuscript is reader-friendly is to have someone who is unfamiliar with the topic read the manuscript and provide candid feedback and suggestions regarding the flow of information.

Albert Einstein has been quoted as saying “Everything should be made as simple as possible, but not one bit simpler.” Although we previously stated that authors should attempt to use simple words, we discourage the use of clinical jargon or terminology that may not be understood by other clinicians (including those external to physical therapy). This commonly occurs when describing therapeutic exercise (e.g. birddog, clamshell). Authors are also encouraged to minimize abbreviations throughout the manuscript. The use of common abbreviations, such as ACL (anterior cruciate ligament) or LBP (low back pain), are often familiar enough to readers and do not distract from the context of the sentence. Uncommon abbreviations or abbreviations specific only to the manuscript may confuse the reader and require consistent referral to the original use to remember the meaning.

**Table 1. Ten Common Manuscript Mistakes**

| 1. | Ignoring standardized format specifications |
| 2. | Introduction does not logically progress to a clear purpose statement |
| 3. | Use of single sentence paragraphs or bullet points |
| 4. | Use of clinical jargon or terminology that may not be understood by the reader |
| 5. | Overuse of abbreviations or use of abbreviations that may not be familiar to the reader |
| 6. | Use of terminology reserved for discussing statistical analyses (e.g. significant relationship) |
| 7. | Formatting the introduction or discussion in a manner consistent with that of an annotated bibliography |
| 8. | Not providing estimates of reliability, validity, or clinical utility for outcome measures |
| 9. | Not including a sample size estimate |
| 10. | Overgeneralization of findings |

**Language**

The *International Journal of Sports Physical Therapy* encourages submissions from individuals around the world and appreciates that English may not always be the author's primary language. At times, even the best ideas may be lost in translation. As previously stated, scientific writing is a skill that is not often an emphasized component of most professional education programs. In instances where authors may not have as much experience with scientific writing or when the English language is not the author's primary language, authors are encouraged to obtain assistance from an individual who can contribute to the writing quality. Often that individual with scientific writing skills can be a co-author or recognized in the acknowledgements section of the manuscript for their assistance. Fee-based services also exist to facilitate the production of manuscripts for publication, but there should be some acknowledgement of individuals or entities that may have an interest in publishing findings. Industry support and any potential conflict of interest should be disclosed. Authorship, however, should be consistent with the guidelines of the International Committee of Medical Journal Editors (www.icmje.org) and all listed authors should have made significant contributions to the design, interpretation and dissemination of the results.

Another component of scientific writing skills is the ability to interpret and convey information relative to the statistical analysis portion of the manuscript. Although this will be further discussed in the Specific
Components section of this manuscript, there are common misuses of terminology reserved for describing statistical analyses. Often authors will use the words significant, associated, or relationship in a manuscript when describing things other than a statistical analysis. "Significance" implies statistical significance and can often be substituted with the word substantial or considerable. Statistical significance indicates a low possibility that the results were not found by chance, thus, if the study was repeated, similar results would likely be found. Statistical significance does not imply importance. Association and relationship are used to describe the correlation between two variables. If a definitive relationship exists between two variables, a point estimate of the correlation should be provided using a referenced manuscript. If the relationship between two variables has not been established in the literature, or based on clinical intuition, authors are encouraged to state a "relationship may exist." Finally it should be stated that research does not prove anything, nor is there an implication of cause and effect. A common example is the relationship between shoe size and cognitive ability in children, but large feet do not cause a person to be smarter (but older children have bigger feet and thus, perform better on some tests).

Finally, the interpretation of the results should not be overstated. A mistake that many young investigators make is to conclude that there was an effect when the results demonstrated otherwise. Or, the author may indicate that a significant difference is interpreted as an important change. An example of the latter is when an intervention resulted in a 3-degree range of motion change of the shoulder. Although the results are statistically significant, the author should interpret the meaningfulness of that change in relation to the error associated with the measurement technique or related to a clinical context. The minimal detectable change and minimal clinically important difference will be further discussed in a subsequent section. Reviewers are very cautious about the interpretation of the analysis and the clinical conclusions that may be drawn.

**Consider peer-review process**

A component of manuscript publication is peer-review, which requires a reviewer to read the manuscript, provide comments and suggestions, and make recommendations for publication, revision, or rejection. Generally an editor assigns the manuscript to two or more reviewers and they may or may not be blinded to the authors' identity, depending on the journal and its policy. Reviewers are chosen based on expertise, familiarity and work in a specific area, and availability. Since manuscript reviewers are volunteers who typically have other primary jobs, life obligations such as family and friends, as well as hobbies beyond reviewing manuscripts, authors are encouraged to take steps to facilitate the review process.

The *International Journal of Sports Physical Therapy* has developed specific Instructions to Authors (http://www.spts.org/assets/files/Instructions_IJSPT_7_11.) that provides readers with submission standards and author resources. Potential authors should familiarize themselves with these guidelines. The instructions outline specific criteria relevant for each manuscript category (Original Research, Systematic Review of the Literature, Clinical Commentary/Current Concept Review, Case Reports, Clinical Suggestion/Unique Practice Technique, Technical Note) and include relevant checklists to ensure authors address all necessary components of manuscript submission.

Regardless of the manuscript type, all submissions should follow format specifications outlined by the journal. A summarized version relevant to the *International Journal of Sports Physical Therapy* is outlined in Table 2. Potentially the most critical aspect to facilitate peer-review is the inclusion of page and line numbers that allows the reviewer to provide the author with line-by-line content, writing, or organizational suggestions. The feedback that can be provided on a line-by-line basis is far more valuable for the author than general comments. This method also allows authors to specifically address reviewer comments on a line-by-line basis, thus facilitating manuscript resubmissions. Since reviewers are not copy editors, authors are also encouraged to ensure there are minimal spelling or grammatical errors prior to submission. These errors tend to detract from the reviewers' ability to review the content of the manuscript. Thus, having an individual proof read the manuscript prior to submission is encouraged.

**SPECIFIC SECTIONS**

**Introduction**

The introduction is a critical component that provides the relevant background information and the
rationale for the study. A concise review of information pertinent to the topic of the manuscript should be provided. The intent is not to present a comprehensive review of all knowledge related to the topic of interest. A common error is to format the introduction similar to an annotated bibliography where specific studies are discussed in detail without attempting to summarize findings across a number of studies. Review papers generally include a more thorough overview of a topic area, and should be submitted in an appropriate format to journals that accept that type of manuscript.

The introduction should logically progress to the purpose statement. The analogy of a funnel is helpful when thinking of the introduction, which follows a logical sequence from broadly presenting the concept to focusing on a specific knowledge gap, discrepancy between studies, or research question that leads to the purpose statement. The purpose statement should be clearly defined based on the knowledge gap, discrepancy between studies, or the problem. Try to hide the purpose statement and guess what it will be after reading the introduction. This test will determine whether the introduction was adequate since the reader should essentially have an idea of what the purpose of the study will entail. Authors are also encouraged to include a directional hypothesis that includes all outcome variables of interest, as appropriate. For example, the authors should be able to hypothesize that there will be an increase in range of motion following an intervention, rather than merely stating that the intervention would have an effect on range of motion.

Methods
The methods section should detail the specific study design and provide the reader with a step-by-step process of the methodology utilized in the study. The methods section should also be of sufficient detail that the reader could reproduce the methods used in the study. The use of standardized criteria and checklists will ensure authors include all required elements. Specific criteria are dependent on study design and include; randomized clinical trials CONSORT (Consolidated Standards of Reporting Trials), cohort, case control, cross-sectional studies STROBE, diagnostic accuracy STARD (STAndards for the Reporting of Diagnostic accuracy studies), and systematic reviews and meta-analyses PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses). Case reports have a checklist developed by the International Journal of Sports Physical Therapy editorial board. Figures, tables, and appendices can enrich reader understanding while minimizing text. Since case reports often develop in a retrospective manner clinicians are encouraged to use consistent examination techniques and standardized outcomes forms.

A specific statement should be included that clearly indicates subjects gave informed consent and that the study was approved by an institutional review board or similar committee. Case reports should include a statement that the patient was informed that information concerning the case would be submitted for publication and all identifying characteristics should be stripped from the paper. Clinical trials should be registered (clinicaltrials.gov) and there should be a mechanism to track trials using a unique case number that is often reported in the acknowledgements. Finally, any potential conflict of interest and funding should be disclosed and acknowledged.

When utilizing outcome measures it is helpful to provide the reader with information regarding validity and reliability. Reliability measures should include specific point estimates (e.g. ICC3,1 = .97) versus simply stating "good reliability". This method provides the reader with sufficient evidence that the measures are appropriate and provides context for meaningful changes. Authors should also consider including minimal detectable
change (MDC)\textsuperscript{6} or minimally clinically important difference (MCID)\textsuperscript{7}, if known, in order to provide contextual meaning to the outcome measures utilized in the study.

It is also necessary to provide information related to the sample size estimate. Although the sample size estimate is computed in the planning stages of the study, it provides the reader with an idea of the expected change in the outcome variables and how many subjects are needed to observe that change within a particular confidence range. Studies that do not determine sample size prior to data collection may not have a sufficient number of subjects to demonstrate changes that may occur throughout the study.

**Results**
The results section should be dedicated to reporting the results, not the interpretation of the results. It is important to note here that statistics do not “find” or “reveal” things, but may be used to “demonstrate” or “indicate.” The statistical analysis utilized should be based on study design and outcome variables. A good way to determine a logical flow is to examine the methods and analysis and look for parallels in the presentation. For example, if several dependent variables will be examined, use the same order in all three sections, then the reader is expecting a sequential presentation of the results. Authors that may not have strong statistical backgrounds are recommended to consult with another individual with greater expertise, such as a statistician. It is recommended to simply report results as significant or not significant. It is not appropriate to report “almost significant” and authors are encouraged to use caution when reporting trends. When reporting the statistical analysis specific values derived should be provided. An example is to include a specific P-value (i.e. $P = .04$) versus a generic P-value (i.e. $P \leq .05$). Reliability studies should include point estimates (i.e. ICC\textsubscript{3,1} = 0.97) when discussing reliability, not simply stating “good reliability”. Studies with multiple independent and dependent variables often include data that is better presented in a table or graph format. The use of tables or graphs is encouraged when presenting data, but should not duplicate the results in the text.

In addition to reporting statistical significance authors are encouraged to report effect sizes as well as the results in context to the minimal detectable change (MDC)\textsuperscript{6} or minimal clinically important difference (MCID)\textsuperscript{7}. Effect size, minimal detectable change, and minimal clinically important difference provide context to the results and can be used as a comparison between studies. Effect sizes are also a good way to describe the result in a meaningful manner and should be used in conjunction with traditional statistical measures to examine an intervention.

**Discussion**
The purpose of the discussion is to provide context for the results of the study and is often the most difficult portion to write. The discussion should provide an interpretation of the results of the current study as well as a comparison of the findings (corroborate/conflict) with previous studies. Especially important is a scholarly, critical, and referenced analysis of the outcomes or suggestions related to previous evidence and clinical practice. Authors should consider why outcomes occurred and cite with references based on previous evidence.

A common error that occurs in the discussion section is when authors overgeneralize their study findings. This often occurs when discussing the results of a study involving individuals without pathology and suggesting that there is now evidence that a particular intervention is beneficial in a population with a specific pathology. Similarly, defending a conclusion or non-significant statistical results is discouraged. The results reveal whether the difference was potentially due to chance, or from the intervention. If the intervention did not produce the desired outcome, limitations of the study should be presented, but the conclusion should support the statistical results. The discussion section also provides the opportunity to discuss study limitations and suggestions for future studies.

**Conclusion**
The conclusion provides a summary of the current study findings. This is not the section to discuss study limitations, introduce new study findings or to discuss future research directions. The conclusion should be brief and to the point.

**References**
The reference section should be contemporary, high quality (meta-analyses/systematic reviews, random-
ized control trials) sources when possible. References for the *International Journal of Sports Physical Therapy* should be in the correct format (American Medical Association). Additionally, references should be relevant to the manuscript, keeping in mind that more references are not necessarily better. Authors are also encouraged accurately convey information related to each reference and avoid utilizing secondary references, which can lead to errors and overgeneralized suggestions. Authors are encouraged to use referencing software and format to the specifications for the specific journal.

**Tables and Figures**

Tables and figures should be easy to read and contribute to the manuscript by enriching reader understanding while minimizing text. Appropriate formatting guidelines are outlined in the Instructions to Authors (http://www.spts.org/assets/files/Instructions_IJSPT_7_11.pdf). Tables should include group means and statistical measure of variation, such as standard deviation, standard error of the mean, or confidence intervals.

Figures also provide advantages when describing methods or statistical analyses. Photos should have a professional appearance and be taken with a high quality camera in high resolution when possible. Although most mobile phones have integrated cameras the image quality is often inferior to a traditional digital camera. In addition to focusing on the foreground of the figure, authors should also consider the background of the figure. Often photos are taken in busy clinic or laboratory settings and authors should avoid busy backgrounds or other factors that may detract from the original purpose of the photo. The use of a neutrally colored wall or cloth as a backdrop can eliminate busy or unprofessional backgrounds.

**CONCLUSION**

The purpose of this manuscript was to provide suggestions for authors to improve manuscript quality and to avoid common manuscript mistakes prior to submission for review. This was not intended to be a comprehensive resource for scientific writing. Readers are encouraged to also utilize other resources highlighting publication of scientific manuscripts, and tips to improve writing clarity. By avoiding common manuscript mistakes authors will ultimately produce higher quality initial submissions, allowing reviewers to focus on content related comments and suggestions, and produce high quality manuscripts.

**REFERENCES**


ABSTRACT

Purpose/Background: Both forefoot strike shod (FFS) and barefoot (BF) running styles result in different mechanics when compared to rearfoot strike (RFS) shod running. Additionally, running mechanics of FFS and BF running are similar to one another. Comparing the mechanical changes occurring in each of these patterns is necessary to understand potential benefits and risks of these running styles. The authors hypothesized that FFS and BF conditions would result in increased sagittal plane joint angles at initial contact and that FFS and BF conditions would demonstrate a shift in sagittal plane joint power from the knee to the ankle when compared to the RFS condition. Finally, total lower extremity power absorption will be least in BF and greatest in the RFS shod condition.

Methods: The study included 10 male and 10 female RFS runners who completed 3-dimensional running analysis in 3 conditions: shod with RFS, shod with FFS, and BF. Variables were the angles of plantarflexion, knee flexion, and hip flexion at initial contact and peak sagittal plane joint power at the hip, knee, and ankle during stance phase.

Results: Running with a FFS pattern and BF resulted in significantly greater plantarflexion and significantly less negative knee power (absorption) when compared to shod RFS condition. FFS condition runners landed in the most plantarflexion and demonstrated the most peak ankle power absorption and lowest knee power absorption between the 3 conditions. BF and FFS conditions demonstrated decreased total lower extremity power absorption compared to the shod RFS condition but did not differ from one another.

Conclusions: BF and FFS running result in reduced total lower extremity power, hip power and knee power and a shift of power absorption from the knee to the ankle.

Clinical Relevance: Alterations associated with BF running patterns are present in a FFS pattern when wearing shoes. Additionally, both patterns result in increased demand at the foot and ankle as compared to the knee.

Key words: barefoot running, biomechanics, running, strike pattern
INTRODUCTION

Running barefoot is not a new concept; yet relatively few people choose to run barefoot (BF) on a regular basis. BF running has been used as a training method for years partially due to the belief that it improves performance and strengthens the intrinsic and extrinsic muscles of the foot. A number of recent studies focusing on BF running have demonstrated distinct differences in lower extremity mechanics and muscle activity when compared to shod running. BF running has received much attention due to these differences and how they may be related to injury or performance. When running BF, there is a significant reduction in the impact peak of the vertical ground reaction force (GRF) with a subsequent increase in impulse. These changes likely contribute to a reduction in the high mechanical stresses that occur during repetitive strides. For example, in a related concept, subjects with knee osteoarthritis walking BF have a significant reduction in joint loads at their knees and hips compared to walking in their normal shoes.

While benefits have been suggested, there are potential risks associated with running BF. Many believe the risks are due to decreased external protection of the sole of the foot and lower reduction of shock transmission when compared to running with shoes. Although forces are reduced under the heel in BF runners, forces are increased under the forefoot, both of which are the result of associated changes in foot strike pattern. Repetitive impact forces from running may cause discomfort and further result in other lower limb overuse or stress injuries.

Running shoes provide many benefits to runners such as protection of the sole of the foot from the hard ground and unpredictable surfaces. Traditionally, sport shoes have been designed in an attempt to augment specific sports performances and to help prevent athletic injuries. For example, cushioned running shoes provide lower extremity shock attenuation while motion control running shoes decrease rearfoot eversion. Running shoes have been shown to reduce impact peak of the GRF by 22% when compared to running BF. While running shoes are associated with a number of beneficial effects, a large number of injuries to the foot have been associated with poorly-fit running shoes. This has led researchers and shoe companies to investigate the need for shoe designs with less motion control or cushion (minimalist footwear).

Recently, shoe companies have begun developing shoes that are designed to mimic BF running by making them lighter and thinner. One such shoe was effective in imitating the BF condition and at the same time provided a small amount of protection. However, peak vertical GRFs were higher in minimalist shoes compared to BF which may be due to comfort and the runners’ ability to increase push off force when compared to BF running.

BF running is associated with a change to midfoot strike or forefoot strike (FFS) pattern. Running with a FFS pattern results in decreased loading rates and decreased work at the knee when compared to running with a rearfoot strike pattern (RFS). While work at the knee is decreased in a FFS pattern, work at the ankle is increased. Further, a FFS pattern reduces both the magnitude and the rate of loading of the skeletal forces on the tibia produced during BF running. While FFS reduces stress in the lower extremity during initial contact it places increased demand on the achilles tendon and plantar fascia which may lead to pathologies in these structures. Conversely, RFS runners have a greater work demand at the knee when compared to FFS. For these reasons, it is often recommended that runners with knee pain or pathology adopt a midfoot or FFS pattern. However, it is not currently known whether running BF changes biomechanical factors of the lower extremity differently than adopting a FFS pattern while in shoes.

The purpose of this study is to compare the lower extremity biomechanics of shod RFS running to those occurring during shod FFS and BF conditions. The authors hypothesized that compared to the shod RFS condition: 1. Shod FFS and BF conditions will demonstrate increased plantarflexion, knee flexion and hip flexion angles at initial contact, 2. Shod FFS and BF conditions will demonstrate an increased joint power absorption in the plantarflexors and decreased joint power absorption in the knee and hip extensors and 3. Total lower extremity joint power will be lowest in the BF condition and highest in the shod RFS condition.
METHODS

Runners for this study were recruited and randomly selected from the University and local running clubs. The study included a total of 10 male and 10 female runners ranging in age from 20-30 at the time of data collection (Table 1). All runners were experienced runners who ran at least 6 miles per week and at least 3 days per week. All subjects ran with a RFS pattern when wearing shoes and did not regularly train or run in BF or FFS conditions. Subjects were excluded from this study if they had any cardiovascular or neurological compromise, current lower extremity musculoskeletal injury or pain, joint replacement or joint fusion. Each subject gave their written informed consent for participation in the study, which was approved by the University and Medical Center Institutional Review Board.

Subjects eligible for participation in the study completed a 3-dimensional running analysis. Two standing calibration trials were collected during which static joint (bilateral greater trochanters, right medial and lateral knee, right medial and lateral maleoli, right medial and lateral forefoot) and segment tracking (distal, proximal and lateral calcaneus, shank, thigh and pelvis) retroreflective markers were placed on the right lower extremity. One static trial was performed while the subjects were wearing New Balance 825 running shoes with the posterior and lateral heel cut out. These are a neutral shoe with a single density midsole. All subjects wore the same shoes during both of the shod trials. The second static trial was performed with the subject BF.

The static joint markers were used to establish joint centers and segment coordinate systems. The static joint markers were removed before dynamic data collection, and subjects were allowed to run along the runway as many times as necessary to feel comfortable with the markers and the lab environment. The subjects were asked to run along a 20 meter runway at a speed of 3.35 m/s (±5%). Running speed was measured using photocells 6 meters apart. A fixed pace was chosen to reduce differences in lower extremity biomechanics related to speed. All runners were comfortable running at this pace, particularly since it was over a short distance and there was time provided for rest between trials. Kinematic data were collected at 240 Hz with an 8-camera Qualisys® motion analysis system (Qualisys® Inc., Gothenburg, Sweden). Three-dimensional coordinates for each maker were reconstructed and filtered at 12 Hz. Two forces plates (AMTI®, Watertown, MA) mounted in the floor of the runway recorded ground reaction forces (GRF) at a sampling frequency of 1200 Hz. The GRF data was filtered at 50 Hz with a second-order recursive Butterworth filter (C-motion® Inc., Bethesda, MD).

All subjects ran in each of 3 running conditions: RFS, FFS and BF, performing 10 trials of each. The order of running conditions was established by flipping a coin to determine the shod or BF condition. Each foot strike pattern within the shoe condition was determined second. All runners were naturally RFS and employed a RFS pattern in the shod condition. In the BF condition, each runner was instructed to run down the runway without any instruction as to how to foot strike. In the FFS condition, subjects were simply instructed to “run on your toes”. No training was provided for the runners for either the FFS or BF conditions. A total of 10 successful trials for each condition using the right lower extremity were collected for each subject. Subjects had a chance to rest in between each trial. A trial was considered acceptable if the subject ran without altering their stride characteristics over the force plates within the given velocity range, and their entire right foot hit one of the force plates.

Pelvis, thigh, shank, and foot segments were created. All data were time synchronized at the time of collection through system hardware. Data were further analyzed between initial contact and toe off and

<table>
<thead>
<tr>
<th>Gender</th>
<th>Age (years)</th>
<th>Body Mass (kg)</th>
<th>Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male (n=10)</td>
<td>25.40 ± 2.01</td>
<td>79.99 ± 9.53</td>
<td>1.81 ± 0.07</td>
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<tr>
<td>Female (n=10)</td>
<td>24.10 ± 1.37</td>
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<td>1.63 ± 0.07</td>
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normalized to 100 data points, each representing 1% of the stance phase of running. Utilizing Visual 3-D software (C-motion® Inc., Bethesda, MD), joint rotations were calculated via Cardan sequencing where motion about the X-axis was defined as flexion/extension at the hip and knee and plantarflexion/dorsiflexion for the ankle. Motion about the Y-axis was defined as abduction/adduction at the hip and knee, and internal rotation/external rotation at the ankle. Finally, motion about the Z-axis was defined as internal rotation/external rotation at the hip and knee, and inversion/eversion at the ankle. Mean curves from 10 trials were created for each condition for hip, knee, and ankle motion in the sagittal plane. Joint powers were calculated using standard inverse dynamics.

STATISTICAL METHODS
After collection, all trials were analyzed in order to determine if strike pattern matched the assigned condition. Strike index was used to verify strike pattern in each condition. Strike index was defined as the position of the center of pressure relative to the long axis of the foot. A value of 0% represents an extreme heel strike and 100% represents extreme toe striking. For the purposes of this study, RFS was defined as 0-33%, 34-66% was considered midfoot strike and 67-100% was considered FFS. The dependent variables were the angle of plantarflexion, knee flexion, and hip flexion at initial ground contact and peak negative sagittal plane joint power (absorption) at the hip, knee and ankle during stance. A series of one-way ANOVAs were employed to compare variables of interest (α≤0.05). If significant differences were determined in each one-way ANOVA, post-hoc paired t-tests (α≤0.05) were utilized to determine specific differences.

RESULTS
Strike indices were different between conditions (Table 2). A significant difference (p=0.00) was found in ankle angle at initial contact. Individual comparisons revealed the RFS pattern resulted in a dorsiflexed position (14.85° ± 6.15°) while the FFS pattern resulted in a more plantarflexed position (–12.46° ± 6.67°) (Figure 1). The BF condition demonstrated a dorsiflexed position (0.03° ± 7.29°) compared to shod FFS condition and less ankle dorsiflexion when compared to the shod RFS condition. There were no differences between conditions in knee (p=0.84) or hip angles (p=0.19) at initial contact (Table 3).

When comparing peak ankle power absorption, all conditions were significantly different (p=0.00) with the FFS condition (–9.58 ± 2.21 W/kg) resulting in the greatest ankle power absorption and the shod RFS condition resulting in the least (–5.72 ± 2.33 W/kg).

<table>
<thead>
<tr>
<th>Table 2. Strike Indices during all conditions.</th>
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<tr>
<td></td>
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<tr>
<td>Mean</td>
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<tr>
<td>Range</td>
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<tr>
<td>Footstrike patterns</td>
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<tr>
<td>RFS</td>
</tr>
<tr>
<td>Midfoot</td>
</tr>
<tr>
<td>FFS</td>
</tr>
</tbody>
</table>

RFS= Shod rearfoot strike condition; FFS= Shod forefoot strike condition; BF= Barefoot running condition
*Definitions of footstrike patterns: RFS= 0-33%; Midfoot= 34-66%; FFS= 67-100%
(Figure 2). The BF condition ($-6.58 \pm 1.70$ W/kg) was significantly different from the other 2 conditions (Table 3).

All conditions were significantly different when comparing peak knee ($p=0.00$) and hip ($p=0.01$) power absorptions, the FFS condition (knee = $-6.24 \pm 2.66$ W/kg, hip = $-1.07 \pm 0.75$ W/kg) resulted in the least power absorptions and the shod RFS condition resulted in the greatest (knee = $-13.48 \pm 4.56$ W/kg, hip = $-2.63 \pm 1.58$ W/kg) (Figure 3). The BF condition was significantly different from both conditions at the knee ($-7.93 \pm 2.73$ W/kg) and different from the FFS condition only at the hip ($-1.83 \pm 1.72$ W/kg) (Table 3).

Total joint power absorption differed between conditions ($p=0.00$) with the shod RFS condition demonstrating the largest magnitude absorption ($-21.83 \pm 5.46$ W/kg) compared to the FFS ($-16.88 \pm 3.48$ W/kg) and the BF conditions ($-16.35 \pm 3.11$ W/kg) (Figure 4).

**DISCUSSION**

The purpose of this study was to compare lower extremity mechanics that occur during running with...
a RFS pattern compared to those that occur when running with a FFS pattern and those occurring in a BF condition. In general, FFS and BF conditions demonstrated similar mechanical changes when compared to the shod RFS condition. Specifically, BF and FFS runners demonstrated increased plantarflexion at initial contact, increased peak ankle power absorption and decreased peak knee and hip power absorption. This is consistent with what has been previously shown in FFS runners and BF runners.\textsuperscript{17,18}

In both FFS and BF running the forces at initial contact are transmitted through the comparably smaller midfoot bones and muscles rather than through the calcaneus, talus and tibia directly. While a structurally sound foot may be able to absorb these forces effectively, it is likely that different foot types may respond differently to these increased forces to the forefoot. Foot type was not assessed in the current study so it is unclear which specific foot types would be more vulnerable. The difference between FFS and RFS ankle angle at initial contact was much greater than the difference between BF and RFS. This results in a much greater shortening of the gastrocnemius and soleus, which may require the muscle to work harder due to the compromised length tension relationship.\textsuperscript{19} Additionally, because of the eccentric to concentric transition that occurs at midstance,\textsuperscript{20} the muscles of the calf may be further stressed during midstance.

There was no increase in knee flexion angle at initial contact in the BF or FFS conditions. While the values in the current study are lower than previously reported,\textsuperscript{18} they are consistent with the findings presented in recent reports that examined BF runners.\textsuperscript{17}

If the ankle is in more plantarflexion at initial contact, the knee would be in more flexion in order to establish the strike position closer to the projection of the center of mass (COM). If runners are not habitual FFS or BF runners, they may not change the knee angle, resulting in a strike further anterior to the COM projection. Manipulation of strike position relative to the COM independent of strike pattern (FFS versus RFS) may help clarify if strike pattern or strike position is the more important factor in changes in lower extremity mechanics. For example, increasing stride frequency decreases anterior strike position and increases knee position at initial contact.\textsuperscript{21} These changes are present without a change in foot strike pattern. Finally, the decrease in the passive tension in the gastrocnemius may result in more extension of the knee at initial contact in inexperienced FFS or BF runners. Modification of the complex interactions of stride frequency, stride length, foot strike pattern, and lower extremity mechanics as they relate to running performance and injury is not yet fully understood. Simply instructing runners to “run on your toes” or “on the ball of your foot” may not result in the desired strike pattern and perhaps place some individuals at risk for injury if the change in strike pattern is incomplete or incompatible with the runner’s lower extremity structure.

Interestingly, the FFS and BF conditions did not result in changes compared to the RFS condition when considering hip angle at initial contact. While runners during the BF condition demonstrated a trend toward decreased hip flexion, these differences were not significant. Decreased hip flexion is consistent with modification of the position of the COM projection more posteriorly under the body. Because trained BF runners strike in less plantarflexion than FFS, they would be less likely to strike anteriorly. With no concurrent increase in knee angle at initial contact, the hip would need to remain in less flexion, bringing the COM posteriorly and allowing the forefoot to contact the ground. This may contribute to the concurrent increase reported in peak vertical ground reaction force in FFS.\textsuperscript{18} This increase in vertical GRF combined with the more vertical orientation of the lower extremity segments in FFS and BF running, there is potentially increased compressive forces compared to torsional forces in the ankle, knee and hip joints. Additionally, this may partially

\hspace{1cm}

\textbf{Figure 4. Total Power absorption across all conditions.}
explain the reported decrease in the deceleration component of the posterior GRF.

The FFS pattern and BF conditions both reduced the peak knee extensor power. FFS demonstrated the greatest reduction in magnitude. These findings are consistent with what has been previously reported in research performed on forefoot strikers. Comparatively, the FFS conditions demonstrated the greatest reduction in knee extensor power. It is important to note that these changes in knee power occurred independent of changes in knee position at initial contact. Since there were no changes in knee position and similar magnitude of the vertical GRF, the differences in knee power suggest that the line of the vertical GRF may be passing closer to the knee joint center throughout the stance phase. Therefore, it may be important to evaluate contact forces in the joints of the lower extremities during BF and FFS running. Further, changes in the moment arm of the vertical GRF have implications for extensor demand and metabolic cost.

Plantarflexion power (absorption) was significantly greater in FFS and BF conditions when compared to the shod RFS condition. FFS had the greatest increase in ankle power absorption. This is likely present due to the fact that running in the BF condition resulted in a more midfoot strike pattern that reduces the load on the plantarflexors. In fact, running BF resulted in an average strike index of 45.7% but only 60% of the runners in this condition actually adopted a midfoot or FFS pattern. This suggests that while BF running, on average, results in a different strike pattern, a number of runners still maintain a RFS pattern. Therefore, a switch to running BF may not sufficient to make comprehensive changes in the lower extremity mechanics in all runners. Running BF without subsequent changes in strike pattern is unlikely to result in reduction of injury or other benefits. In contrast, 100% of the subjects ran with a midfoot or FFS pattern in the FFS condition with an average strike index of 65.8%. It is important to note that none of the subjects in the current study were experienced or trained BF runners. Further study of whether trained BF runners demonstrate similar strike patterns as those observed in the current study will help to clarify the potential changes associated with BF running.

A midfoot strike pattern potentially places the perpendicular position of the vertical GRF further from the ankle joint center compared to FFS. While this may reduce the vertical impact through the long axis of the metatarsals, it is likely to increase the torsional forces imparted on the midfoot and forefoot as a result of changing the “gear ratio” as described by Braunstein et al. These torsional forces are most commonly directed toward dorsiflexion of the metatarsals on the cuboid and cuneiforms. The morphology of these plane joints help to establish stability in the midfoot. However, it is not known how these joints respond to repetitive dorsiflexion stress associated with midfoot and forefoot strike patterns. This may partially explain some of the recent evidence associating strike pattern and metatarsal stress fractures in BF runners.

CONCLUSION
When compared to RFS running, FFS and BF running conditions both resulted in reduction of total lower extremity power absorption particularly at the knee and a shift in power absorption from the knee to the ankle. While these reductions may be beneficial in isolation, the increase in power absorption at the distal segments may result in increased risk of injury at the foot and ankle. Special care should be taken when adopting a FFS or BF running style in an attempt to improve performance or reduce lower extremity injury risk. Both FFS and BF running appear to result in significant changes in lower extremity and power absorption when compared to RFS running. In fact, these differences are more pronounced in the FFS condition as compared to the BF condition. Therefore, it may not be necessary to run BF or in minimalist shoes in order to gain potential benefits. However, the larger increase in ankle power in FFS running may be potentially injurious. Long-term prospective studies are necessary to determine what benefits may be present as a result of FFS or BF running styles or how these running patterns may affect injured runners or runners with chronic problems such as osteoarthritis.

REFERENCES


ABSTRACT

Objective: Determine the reliability of two different modified (MOD1 and MOD2) testing methods compared to a standard method (ST) for testing trunk flexion and extension endurance.

Participants: Twenty-eight healthy individuals (age 26.4 ± 3.2 years, height 1.75 ± m, weight 71.8 ± 10.3 kg, body mass index 23.6 ± 3.4 m/kg²).

Method: Trunk endurance time was measured in seconds for flexion and extension under the three different stabilization conditions. The MOD1 testing procedure utilized a female clinician (70.3 kg) and MOD2 utilized a male clinician (90.7 kg) to provide stabilization as opposed to the ST method of belt stabilization.

Results: No significant differences occurred between flexion and extension times. Intraclass correlations (ICCs3,1) for the different testing conditions ranged from .79 to .95 (p < .000) and are found in Table 3. Concurrent validity using the ST flexion times as the gold standard coefficients were .95 for MOD1 and .90 for MOD2. For ST extension, coefficients were .91 and .80, for MOD1 and MOD2 respectively (p < .01).

Conclusions: These methods proved to be a reliable substitute for previously accepted ST testing methods in normal college-aged individuals. These modified testing procedures can be implemented in athletic training rooms and weight rooms lacking appropriate tables for the ST testing.

Key Words: Core, stabilization, trunk endurance

Level of Evidence: 3
INTRODUCTION
Trunk/core stability and endurance have been investigated with respect to potential contribution to injury and athletic performance in activities such as running and jumping. Workers who reported low back pain (LBP) had decreased trunk extensor endurance.\(^1\) This lack of endurance appears to be a predictor of future occurrences of LBP.\(^2,3\) Imbalance between flexion and extension trunk muscle endurance times may be even more important than isolated trunk endurance deficits.\(^4\) The cause of LBP appears to be associated with an imbalance of flexion-extension endurance times, with the extensors having less endurance than the flexors.\(^4\)

Expensive isokinetic testing has been used to assess strength and work of the trunk musculature.\(^5,6\) This type of testing, although able to provide the clinician with discrete data, is expensive, time intensive, and requires a lot of space. Less expensive isometric trunk endurance testing is more clinically available and practical.\(^3,7\) This type of testing also affords more clinical applicability.

Acceptable clinical tests that measure the strength or power component of trunk stability have been recently advocated because they may be more useful,\(^8\) and may better mimic the demands imposed by sport.\(^9\) While strength and power are more likely representative of athletic explosive demands, trunk strength appears to have little, or a very weak, relationship with low back health.\(^10\) Trunk endurance testing, however, continues to be warranted and necessary for at least two reasons. One, these muscles are predominantly type I muscle fibers\(^11,12\) that appear to become more anaerobic as a result of deconditioning.\(^10\) Two, trunk muscles’ maximum isometric strength was not associated with LBP in athletes. However, the same authors found a relationship between trunk muscle endurance imbalance and LBP in the same athletes.\(^13\) Additionally, balance between the various trunk muscle endurance values was found to be a better predictor of LBP than strength alone.\(^4\)

Normative values exist for trunk endurance assessments among college-aged students with no history of LBP,\(^14\) as well as college-aged male rowers.\(^15\) These methods used for testing trunk endurance demonstrate excellent reliability.\(^14,15\) Implementation of these testing techniques in some rehabilitation and athletic training environments is, however, potentially limited because these tests require appropriate tables and the use of multiple belts. Therefore, the use of these methods in settings without the correct equipment or with large groups may be limited. The purpose of this research was, therefore, to compare the reliability of modified trunk flexion and extension testing set-ups to previously established testing procedures. Concurrent validity between endurance times (in seconds) using the standard method and the modified methods was also examined.

METHODS
Participants
An a priori power analysis showed that a sample size of 25-30 individuals would be needed to achieve a moderate effect size (\(\text{d} = .60\)) and 80% power. The participants consisted of 28 athletic individuals (14 females and 14 males), with no history of hip or LBP within the past 6 months, no history of hip or lumbar surgery, and no experience with the testing methods (Table 1). Participants were physically active in aerobic and/or strength training (running, basketball, and/or weightlifting) one to four times per week. The study was approved by the Wichita State University Institutional Review Board for the Protection of Human Subjects. Informed consent was obtained. Participant rights were protected and the investigation conformed to the protocol and ethical and humane research principles.

Methods
Written information and oral instructions were given before each test. All participants were timed during the performance three techniques (standard [ST],

<table>
<thead>
<tr>
<th>Table 1. Demographic Characteristics of Participants (n = 28).</th>
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<tbody>
<tr>
<td>Age (years)</td>
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<tr>
<td>Mean ± SD</td>
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<tr>
<td>(Minimum – maximum)</td>
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<tr>
<td>Abbreviations: SD= standard deviation; m= meters, kg= kilograms; BMI= body mass index</td>
</tr>
</tbody>
</table>
modification one [MOD1], modification two [MOD2]) for both flexion and extension at one-week intervals (Figure 1). Testing type (flexion or extension) was randomly selected at the first session. Testing order was randomly determined at each testing session. A 10-minute dynamic warm-up (easy jogging, dynamic movement drills including marching, marching toe touches, and hurdle step overs) was performed by subjects at the beginning of each session. Participants rested 5 minutes between flexion and extension testing at all sessions. The MOD1 and MOD2 techniques used two different clinicians, one female, MOD1, and one male, MOD2, as described below to provide stabilization in lieu of belts for the ST technique. The clinician not providing stabilization performed the endurance timing as per previous investigation\textsuperscript{16} and specifically described below.

Maintaining the test position as long as possible was encouraged prior to all testing, using standardized instructions. Participants were not encouraged during testing. Each participant performed one trial of each testing method. Participants were informed of their times after study completion. Participants were encouraged to maintain their current activity level between testing sessions, specifically for trunk muscle activity. This included specific instruction not to change the current frequency or intensity of the aerobic, anaerobic, weightlifting activities.

**Trunk Extension Testing Procedures**

Standard testing for trunk extension was performed according to McGill et al’s modification.\textsuperscript{14} The original method, from which this modification was modeled, is a reliable measure of back extensor endurance.\textsuperscript{1} For all trunk extension testing, participants were instructed to lie prone. The lower body was fixed to the table surface via straps at the ankles, knees, and hips for standard testing. The upper body (from just above the level of the anterior superior iliac crest) was off the surface of the plinth. Participants held their upper body off the end of the table by pushing with their extended arms on a chair directly below them. Participants were instructed to maintain the horizontal position for as long as possible once testing commenced. At the initiation of the test, the upper limbs were lifted off the chair and crossed over the chest with the hands resting on the opposite shoulders. A stopwatch was used to time from the instant the upper limbs were lifted off the chair and crossed over the chest (and the participant assumed the horizontal position) as described above until the participant visually deviated from the horizontal plane. The same procedures were used for all methods of measuring extension.

The modified testing procedures used a clinician to hold the participants’ lower extremities down, replacing the straps used during the standard procedure. A clinician lay across the backs of the lower extremities so that the middle of the clinician’s trunk was over the middle of the participant’s posterior knees (Figure 2). The clinician (either MOD1 or MOD2) not providing stabilization to the participant measured the endurance time. This clinician stood to the participant’s side and used the above-mentioned criteria of the participant’s visually deviating from the horizontal plane as the criterion for ending the extensor endurance test.

The MOD1 technique utilized a female clinician (age 26 years; height 1.80 m and weight 70.30 kg) and the
MOD2 technique utilized a male clinician (age 25 years; height 1.93 m and weight 90.70 kg) to provide stabilization. None of the participants related any complaints regarding the modified testing procedures.

**Trunk Flexion Testing Procedures**

Standard testing for trunk flexion was performed according to previously published methods. For all trunk flexion testing, participants were positioned supine, with both hips and knees flexed to 90 degrees, trunk inclined at 60 degrees resting on a prefabricated wedge. Stabilization was achieved with a belt around the table and over the dorsum of the feet (with shoes on) for the standard method. Participants crossed their arms across the chest, placing their hands on opposite shoulders, in a manner comfortable to them. Participants maintained their body position for as long as possible after the wedge was moved back 10 cm. Time was measured from the instant the prefabricated wedge was moved back until the participant visually reestablished contact with the wedge. This was the same for all methods.

Modified testing procedures used a clinician to hold the participants' feet rather than using straps (Figure 3). The clinician (either MOD1 or MOD2) not providing stabilization to the participant measured the endurance time. This clinician stood to the participant's side and used the above-mentioned criteria of the participant's visually re-contacting the wedge as the criterion for ending the endurance test.

**Statistical Analyses**

Means and standard deviations for all endurance measurements were generated. Repeated measures analyses of variance (ANOVA) with Bonferroni correction were used to analyze differences in mean flexion and extension times. The intraclass correlation coefficients (ICCs) were used to assess reliability between test methods. Pearson’s *r* was used to analyze concurrent validity between the gold standard (ST times) and times using the modified approaches. SPSS V 17.0 (Chicago, IL) was used to analyze the data. Alpha level was set at 0.05.

**RESULTS**

The mean endurance times for the three methods assessing flexion endurance time ranged from 304.73 ± 207.32 seconds (MOD1 flexion) to 344.26 ± 217.09 seconds (MOD2 flexion). Mean endurance times ranged from 141.12 ± 50.44 seconds (MOD1 extension) to 148.87 ± 43.68 seconds (MOD2 extension) (Table 2). Means for flexion and extension times were not significantly different. Intraclass correlations (ICCs) for the different testing conditions ranged from .79 to .95 (p < .000) and are found in Table 3. Concurrent validity using the ST flexion times as the gold standard coefficients were .95 for MOD1 and .90 for MOD2. For ST extension, coefficients were .91 and .80, for MOD1 and MOD2 respectively (p < .01).

**DISCUSSION**

Modified stabilization methods appear to be a valid and reliable substitute when standard method equipment is not available. These modified techniques may be utilized by clinicians of different sizes and in different settings. Many rehabilitation settings do...
not have tables that allow a belt to be wrapped under its surface, eliminating the possibility of using the original testing methods. Alternative methods, such as those used in this study, therefore, can be implemented reliably.

The ICCs for flexion and extension are considered moderate to excellent, respectively. Other studies' ICC values are higher because researchers used multiple measurements for each test. To prevent fatigue from interfering with the participants' best effort, time was measured only once for each method at weekly intervals. ICCs using average measures are consistently higher than those measures using single measurements.

The authors of the current study are aware of only one other study that has investigated the correlation between the ST methods and any modification. Inter-rater reliability for the modified testing procedures using a clinician in the same manner as the current study was 0.97 for extension and 0.93 for flexion. Correlation of endurance times for this modified testing with the ST procedure was 0.90 and 0.84 for extension and flexion, respectively. A limitation in the Reiman et al. study was that the clinician providing stabilization was always larger than the participant.

Concurrent validity of the MOD tests with the ST test was determined by the correlation between the extension and flexion times, respectively. The absolute

<p>| Table 2. Mean (±SD) time (seconds) and minimum/maximum values (time in seconds) of the three testing methods (n = 28). |</p>
<table>
<thead>
<tr>
<th>Mean (seconds)</th>
<th>Range</th>
</tr>
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<tbody>
<tr>
<td>ST flexion</td>
<td>339.32 ± 214.47</td>
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<tr>
<td>MOD1 flexion</td>
<td>304.73 ± 207.32</td>
</tr>
<tr>
<td>MOD2 flexion</td>
<td>344.26 ± 217.09</td>
</tr>
<tr>
<td>ST extension</td>
<td>147.22 ± 50.33</td>
</tr>
<tr>
<td>MOD1 extension</td>
<td>141.12 ± 50.44</td>
</tr>
<tr>
<td>MOD2 extension</td>
<td>148.87 ± 43.68</td>
</tr>
</tbody>
</table>

Abbreviations: ST= standard testing procedure; MOD1= modified testing procedure with first clinician (female; height of 1.80 m and weight of 70.30 kg; BMI of 21.6); MOD2= modified testing procedure with second clinician (male; height of 1.93 m and weight of 90.70 kg; body mass index of 24.3).

<p>| Table 3. Reliability of Testing Conditions (n = 28). All ICCs are significant at the P &lt; 0.000 level. |</p>
<table>
<thead>
<tr>
<th>Test condition comparisons</th>
<th>ICC3,1</th>
<th>95% CI</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST – MOD1 flexion</td>
<td>0.95</td>
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<tr>
<td>ST – MOD2 flexion</td>
<td>0.90</td>
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<td>ST-MOD1-MOD2 flexion</td>
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<td>MOD1 – MOD2 extension</td>
<td>0.79</td>
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<tr>
<td>ST-MOD1-MOD2 extension</td>
<td>0.83</td>
<td>.71-.91</td>
<td>20.29</td>
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</tbody>
</table>

Abbreviations: ST= standard testing procedure; MOD1= modified testing procedure with female clinician; MOD2= modified testing procedure with male clinician; ICC= Intraclass Correlation Coefficient; CI= Confidence Interval; SEM= standard error of measure.
value of validity is an accurate indicator of the extent of validity determined as follows: correlation coefficients > .80 indicate high validity, values between .60 and .80 indicate good validity, values between .40 and .59 indicate moderate validity, and values < .40 indicate poor validity.19 Thus, the values from this study show that modified methods are valid measures as efficient as compared to the gold standard (use of belts) and, therefore, may be used instead.

The reliability reported in the current study was lower than previously reported values.14 The testing method in the McGill et al study used only five participants tested consecutively for 5 days and then once 8 weeks later.14 The current study involved more participants (n = 28) and fewer test sessions, which is more likely representative of clinical situations.

Although the clinician who provided stability is not the same as a static belt, no resistance on the part of the clinician was required. The clinician simply lay over the lower extremities (or sat on the feet in the case of flexion) and remained stationary, using his/her body mass as a stabilizing force throughout the test. Neither the clinician nor the participants reported any adverse effects of this method. All of the participants subjectively reported that they were stabilized equally during all sessions.

Limitations
There are a number of limitations in this study that warrant mention. Although these modified testing methods appear to be acceptable alternatives to the ST testing procedure in a normal, asymptomatic population, their applicability in LBP subjects is unknown. Trunk extensor20 and flexor7,20,21 muscle endurance times in subjects with LBP are less than those in the normal healthy population and it is unknown whether this would impact the reliability or validity of the methods. Trunk muscle endurance testing methods have been implemented in different LBP populations.22-24 It remains to be determined whether the modified procedures will compare favorably in a symptomatic population.

The criterion for test termination for measuring flexion endurance was previously established as deviating from the 60-degree angle.14,15 The authors of the current study determined, with pilot testing, that reliability was lower using the criterion of breaking the 60-degree plane in any manner compared to the subject’s breaking the plane by contacting the pre-fabricated wedge. We believe the latter more clearly defines test termination. In pilot testing, it was often difficult to ascertain if the subject broke the 60-degree plane throughout the entire spine. Many subjects would lose lumbar lordosis, yet appear to maintain the 60-degree angle and not contact the wedge. Due to this potential complication in test termination criterion, which was also encountered by Chan,15 the authors decided on the termination criterion being when the subject contacted the pre-fabricated wedge. Although reliability was lower than the initial standardization studies,14 it was still high. The different criterion for test termination may be a factor for the differences seen between the current results and those of Chan14 and McGill et al.15

These modified techniques were found to be reliable methods of testing trunk endurance, allowing for potential use in research to determine normative values for different populations. Future research regarding modified endurance testing methods should investigate the size relationship between the clinician and testing participant in different populations. Determining the ratio of clinician to participant size needed for sufficient stabilization in order to achieve reliable outcomes could provide additional information.

PRACTICAL APPLICATIONS
The modified testing methods employed in this study can be utilized as substitute testing methods in healthy adults when proper tables and belts are not available. Having athletes partner with someone of similar size may provide greater validity, but it is not essential. Multiple athletes can be tested at the same time when the athletes partner together and provide stabilization for each other. These procedures, therefore, could be implemented in most athletic training rooms and weight rooms and afford greater efficiency when testing large groups.

CONCLUSION
The use of the MOD1 and MOD2 procedures to test trunk flexion and extension endurance is a reliable alternative to the ST method. The use of these modified procedures will allow clinicians in settings without appropriate tables to assess trunk endurance times
accurately. Having another individual stabilize participants also allows testing of large groups, such as athletic teams, more efficiently than with standard testing. Further study is necessary to determine these testing procedures’ reliability and applicability with participants with LBP.

REFERENCES
ABSTRACT

Background and Purpose: The potential adverse effects of static stretching on athletic performance are well documented, but still appear to be controversial, especially as they relate to sprinting. The prevalence of this practice is demonstrated by the number of competitive and recreational athletes who regularly engage in stretching immediately prior to sprinting with the mindset of optimizing their performance. The purpose of this study was to examine the effects of acute static, dynamic, and ballistic stretching, and no stretching of the iliopsoas muscle on 40-yard sprint times in 18-37 year-old non-competitive, recreational runners.

Methods: Twenty-five healthy recreational runners (16 male and 9 female) between the ages of 24 and 35 (Mean = 26.76 yrs., SD = 2.42 yrs.) completed this study. A repeated measures design was used, which consisted of running a 40-yard sprint trial immediately following each of 4 different stretching conditions aimed at the iliopsoas muscle and lasting 1 minute each. The 4 conditions were completed in a randomized order within a 2-week time period, allowing 48-72 hours between each condition. Prior to each 40-yard sprint trial, a 5-minute walking warm-up was performed at 3.5 mph on a treadmill. The subject then ran a baseline 40-yard sprint. After a 10-minute self-paced walk, each subject performed one of the 4 stretching conditions (ballistic, dynamic, static, and no stretch) and then immediately ran a timed 40-yard sprint.

Results: There was a significant interaction between stretching conditions and their effects on sprint times, $F(3, 72) = 9.422$, $p < .0005$. To break down this interaction, simple main effects were performed with 2 repeated measures ANOVAs and 4 paired t-tests using a Bonferroni corrected alpha ($\alpha = .0083$). There were no significant differences between the 4 pre-condition times, $p = 0.103$ (Greenhouse-Geisser) or the post-condition times, $p = 0.029$. In the no stretch condition, subjects improved significantly from pre- to post- sprint times ($p < 0.0005$). There were no statistically significant differences in pre- and post-stretch condition sprint times among the static ($p = 0.804$), ballistic ($p = 0.217$), and dynamic ($p = 0.022$) stretching conditions.

Conclusions: Sprint performance may show greatest improvement without stretching and through the use of a walking generalized warmup on a treadmill. These findings have clinically meaningful implications for runners who include iliopsoas muscle stretching as a component of the warm-up.

Level of Evidence: Level 2

Key words: Recreational runners, sprinting, stretching, warm-up

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This study was approved by the university’s biomedical institutional review board and an approved informed consent form was signed by each of the subjects prior to testing.
INTRODUCTION

Stretching as a means of improving athletic performance is a commonly held belief despite a lack of support in current literature. The evidence regarding the adverse effects of static stretching on athletic performance is well documented and readily available, but still appears to be controversial in its acceptance by the athletic and fitness communities, especially as it relates to sprinting. The prevalence of this practice is demonstrated by the number of athletes and non-competitive physically active individuals who regularly engage in stretching immediately prior to activity with the mindset of optimizing their physical capabilities. This mindset can be seen when sprinters and recreational runners stretch various muscles immediately before a race based upon the perception that greater flexibility will improve their performance and perhaps reduce their potential risk for injury. The reason behind this common practice is perhaps tied to tradition. Whereas, some research has indicated no difference in performance as a result of different types of stretching, many authors have shown that certain forms of stretching, most notably static stretching, immediately prior to activity may actually adversely affect performance.

Nelson et al examined the effect of partner-assisted static stretching of the calf and thigh musculature on 20-meter sprint performance and observed significantly slower times among post-stretch trials when compared to no-stretch trials. The prevailing rationale behind these and many other similar findings implicates a decrease in musculotendinous elasticity and subsequent reduction in force production capacity. Kokkonen et al found that maximal muscle strength (one repetition maximum knee flexion and extension) was decreased immediately following static stretching. Additionally, Wilson et al concluded that a stiffer musculotendinous unit resulted in greater force production than one that has decreased stiffness as a result of stretching due to an increased rate of shortening and initial force transmission.

In reviewing the literature on stretching and performance, it seems that the most prominent muscles/muscle groups of the lower limb (quadriceps, hamstrings, gluteus maximus, gastrocnemius) have received much of the attention from researchers, most likely because of their visual and literary prominence. The investigation into the actions of these muscles/muscle groups provides an understanding of muscular contributors to sprinting in terms of many of its major biomechanical components (hip and knee extension, knee flexion, ankle plantarflexion), but fails to address hip flexion. This neglect is unfortunate as hip flexion may have the greatest influence on sprint speed of any segmental body movement and should therefore be the recipient of greater scrutiny. For these reasons, the muscle complex primarily responsible for flexion of the hip, the iliopsoas (IP), is important to focus on during future research concerning stretching and sprint performance.

Illustrating the importance of primary hip flexors in dynamic activity, Yokozowa et al concluded that IP was more active than the gluteus maximus, hamstrings, adductors, rectus femoris, gastrocnemius, soleus, tibialis anterior, and the vasti muscles in running at low, medium, and high speeds. The IP has also been shown to have a greater influence on improving one’s running speed than any other muscle/muscle group and is one of three primary muscles/muscle groups (hip extensors, rectus femoris, and iliopsoas) important for generation of power during sprinting. With this knowledge in mind, it comes as no surprise that Deane et al found that a hip flexor strengthening protocol improved 40-yard sprint times by 0.233 seconds, thereby enhancing performance, in untrained, yet physically active individuals.

While much of the available research has focused on static stretching, other stretching methods may influence performance differently. In competitive sprinters, active dynamic stretching of the major muscle groups of the lower limb has been shown to be advantageous in terms of decreasing 50 meter sprint times. Additionally, dynamic stretching of the lower limbs in professional soccer players has produced faster 10 meter sprint times and greater maximal speed over 20 meters in comparison to no-stretch conditions. In contrast, Shrier conducted a systematic literature review concerning stretching and performance and found conflicting results in examining the effect of dynamic stretching on running speed.

Although there are studies documenting the detrimental effects of static stretching and useful effects of dynamic exercises, to date, no studies have researched...
the acute effects of different stretching protocols, specifically for the iliopsoas muscle, on sprint performance. Given the relative controversy and paucity of literature in this area of study, it was the purpose of this study to examine the effects of acute static, dynamic, and ballistic stretching, and no stretching of the IP on 40-yard sprint times in 18-37 year-old non-competitive, recreational runners.

METHODS

Subjects
Thirty-five students (non-competitive, recreational runners) volunteered for the study, 10 of which were unable to complete the study due to soreness from sprinting. The final pool of 25 subjects included 16 males and 9 females between the ages of 24 and 35 (Mean = 26.76 yrs., SD = 2.42 yrs.). Subjects were not allowed to participate if they were pregnant, currently had a musculoskeletal injury, or a health condition that would affect performance or put the subject at risk for injury. The subjects were asked to maintain normal activity throughout the duration of the study, but were asked to avoid any strenuous work 2 hours prior to any of the 40-yard sprint trials. The study was approved by the university’s biomedical institutional review board and an approved informed consent form was signed by each of the subjects prior to testing.

Procedures
This study was a repeated measures design, which consisted of running a 40-yard sprint trial immediately following each of 4 different stretching protocols. The study was performed on an indoor basketball court in order to standardize environmental conditions. Times were taken using an electronic timing system (Lafayette Instrument Co., Lafayette, IN) mounted to two sets of tripods (one pair each for start and finish). Each pair of tripods had one laser and one reflector connected to a timer which would start/stop when the subject ran through each respective laser beam. Measurements for the 40-yards were made using a standard field tape measure. The trials were completed within a 2 week time period allowing 48-72 hours between each trial.

Prior to each 40-yard sprint trial, a 5-minute warm-up walk was performed at 3.5 mph on a treadmill. Following the warm-up and prior to each of the 4 different stretching protocols targeting the IP muscle, a maximal effort, 40-yard sprint was performed and timed using the electronic timing system. The stretching protocols were no stretch (NS), ballistic stretch (BS), static stretch (SS) or dynamic stretch (DS), and the order of the stretching conditions was randomized.

After the baseline time was collected, the subjects walked at a self-selected comfortable pace for 10 minutes around the perimeter of the basketball courts. During the 10-minute self-paced walk, one of the researchers demonstrated to each of the subjects their randomly selected stretching protocol for the day while the subjects maintained their walking speed. Upon completion of the 10-minute self-paced walk, the subjects performed the designated stretching protocol for 1 minute, and within 60 seconds following the designated stretching condition performed a post-stretch maximal effort, 40-yard sprint.

The pre- and post-stretching 40-yard sprint times were compared to determine the acute effects of stretching the IP on 40-yard sprint times. Results were also compared between conditions to determine if differences existed regarding changes in sprint times between the types of stretching. The subjects were blinded to all 40-yard sprint times until the study was completed.

Stretching Techniques
Stretching was supervised by the investigators for each of the stretching conditions. The holding point for each static stretch was arbitrarily selected by each subject as the point before discomfort. For the NS condition, instructions emphasized that the subjects were not to perform any type of stretching during this time, and subjects were asked to stand at the starting line for 1 minute before the 40-yard dash trial. In the DS condition (Figures 1 and 2), subjects stood parallel to a wall while using the wall to stabilize the body during the stretch. Subjects then flexed the hip and knee as close to the chest as possible. When maximum knee height was reached, subjects forcefully brought the hip into extension. Maintenance of upright trunk posture and avoidance of internal and external rotation of the hip throughout the motion was stressed in order to isolate the IP...
muscle. This motion was performed for 15 seconds on one leg and then the subject switched legs and performed the same motion on the other leg; this was repeated one more time for each leg for a total of 2 repetitions of 15 seconds for each leg.

In the BS condition (Figures 3 and 4) subjects went into a lunge stance with the leg of the hip being stretched behind the subject and minimal knee flexion. While in the lunge position, the subjects lowered their hips until they felt a moderate stretch in their IP muscle. With the subject's IP muscle in the elongated position, the subject oscillated inferiorly for 15 seconds on each leg twice, alternating between legs being stretched. In the SS condition (Figures 3 and 4), subjects assumed the same position as described in the BS, but maintained a single repetition 30 second stretch without oscillating.

STATISTICAL METHODS
To determine the acute effects of various types of stretching on 40-yard sprint times a 2 (time: pre and post-stretch condition) by 4 (stretch condition: NS, SS, BS, and DS) repeated measures analysis of variance (ANOVA) was performed to determine if there was an interaction in the data. In the event an interaction was discovered, post-hoc testing using 2 repeated measures ANOVAs to compare between stretching conditions, and 4 paired t-tests were used.
to compare pre- and post-condition 40-yard sprint times, using a Bonferroni corrected alpha (α = .0083), to determine where the significant differences were located. In addition, a chi-square analysis was done to determine if there was a statistically significant association between soreness/injury and stretching protocol in the total of 10 participants who dropped out due to severe soreness.

RESULTS
There was a significant interaction between stretching conditions and their effects on sprint times, F(3,72) = 9.422, p < .0005 (Table 1). In order to further examine this interaction, simple main effects calculations were performed with 2 repeated measures ANOVAs and four paired t-tests using a Bonferroni corrected alpha (α = .0083). There were no significant differences between the four pre-condition times, p = 0.103 (Greenhouse-Geisser) or the post-condition times, p = 0.029. There was a statistically significant difference between pre- and post-stretch condition times in the NS condition, p < 0.0005, suggesting that sprint times improved in this condition. There were no statistically significant differences in pre- and post-stretch condition times between the pre- and post-times for the static (p = 0.804), ballistic (p = 0.217), and dynamic (p = 0.022) stretching conditions, suggesting that sprint times were unchanged between the 2 trials for each of the 3 stretching conditions. Chi-square analysis revealed no significant difference in sprint times, $\chi^2(3) = .533$, p = .912 between subjects who dropped out secondary to soreness and stretching condition and the subjects who completed the study.

Table 1. Comparison of sprint times by condition

<table>
<thead>
<tr>
<th>Condition (N=25)</th>
<th>Mean +/- SD (Pre)</th>
<th>Mean +/- SD (Post)</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Stretch</td>
<td>5.85 +/- 0.53</td>
<td>5.74 +/- 0.51</td>
<td>&lt; 0.0005*</td>
</tr>
<tr>
<td>Static</td>
<td>5.80 +/- 0.51</td>
<td>5.81 +/- 0.51</td>
<td>0.804</td>
</tr>
<tr>
<td>Ballistic</td>
<td>5.82 +/- 0.52</td>
<td>5.80 +/- 0.52</td>
<td>0.217</td>
</tr>
<tr>
<td>Dynamic</td>
<td>5.78 +/- 0.50</td>
<td>5.83 +/- 0.53</td>
<td>0.022†</td>
</tr>
</tbody>
</table>

* p < .05
† Bonferroni corrected

DISCUSSION
The purpose of this study was to examine the acute effects of various types of stretching conditions of the IP muscle on 40-yard sprint times in recreational runners. The authors found that the SS condition did not adversely affect performance nor were there significant changes in pre-post sprint times in the BS or DS conditions. However, a significant improvement in time from pre- to post-condition was observed in the NS condition. As such, the present study supports other studies found in the literature regarding no effects of acute static stretching immediately prior to sprint performance,5,11,20 but appears to contradict other studies where static stretching was shown to adversely affect sprint times.2,4,21

Because the authors were intent on investigating the acute effects of stretching, we focused our research on one major muscle group (the IP muscle), which has been described by previous authors in the literature to be one of the most important muscles involved in sprinting.16-18 The protocol employed during the current study differs somewhat when compared to other studies found in the literature, in that, the authors of the current study measured the effects of stretching on a dynamic event immediately after stretching (0-60 seconds), whereas other studies investigated the effects of stretching on performance approximately 3-10 minutes following the performance of stretching.3,5,6,11,22,23

Contrary to other research, which included multiple muscles in the stretching protocol, the authors did not find a significant difference between pre- and post-measures of 40-yard sprint times when subjects were stretched using BS, DS, or SS methods.4,6,11,20 In contrast to the current study, Winchester et al reported a 3% decrease in sprint performance for track and field athletes after participating in a static stretching protocol, which was conducted after a 30 minute dynamic warm-up.5 Likewise, Fletcher et al reported an increase in 50-m sprint time (decrease in sprint performance) in a group of competitive track and field athletes after passive static stretching, despite being combined with active dynamic stretching. Conversely, they observed a decrease in 50-m sprint time (improvement in performance) after warm-ups involving static dynamic stretches combined with active dynamic stretches or with the
active dynamic stretches alone. Sim et al reported increases in 20-m sprint times (decrease in sprint performance) when static stretching was performed after dynamic activities in the warm-up, but found that static stretching followed by dynamic activities resulted in repeated sprint performance similar to that obtained when dynamic activities alone were performed.

Little and Williams reported that a static-stretch protocol produced significantly faster runs than did the no-stretch protocol for the 20 m sprint. However, in their study, subjects performed further warm-up activity after the stretching, which may have affected the immediate adverse effects of static stretching that have been previously reported. Vetter reported no changes on a 30-m sprint after static stretching. The subjects in the current study showed significantly faster post 40-yard sprint times when compared to pre 40-yard sprint times only after the NS condition. One possible reason for this improved performance could be that the baseline sprint served as a dynamic warm-up and dynamic warm-ups without stretching have been reported to improve sport specific skills such as sprinting. As such, the rehearsal of specific movement patterns may have helped increase coordination of the subsequent sprint, especially in untrained recreational runners who did not use sprinting as a training method.

McMillian et al revealed that warming the muscle up prior to an activity by engaging in dynamic warm-up exercise facilitates physiological changes that may result in modest performance enhancement. They showed that dynamic warm-up resulted in better performance scores on selected measures of power and agility (T-shuttle run, underhand medicine ball throw for distance, and 5-step jump) relative to static stretching warm-up or no warm-up. In the case of the NS group, the baseline 40-yard sprint may have been enough to facilitate performance enhancement, thereby improving the post NS condition sprint time in the present study.

Another possible reason for improved performance in the NS condition could be that lack of stretching after a dynamic activity may have contributed to a stiffer tendon, which may have correlated with increased performance in force production. A possible reason for this mechanism was proposed by Wilson et al. The authors suggested that for concentric muscle actions, a stiffer musculotendinous system would improve contractile component force production, thus allowing more favorable length and velocity conditions. In other words, a stiffer musculotendinous unit should allow the contractile component to be at a more optimal point on both the force/velocity and force/length curve in terms of force production. Additionally, Rosenbaum et al concluded that stretching impaired force production and hypothesized that the decreased force production was due to mechanical changes such as increased tendon slack.

Burkett et al pointed to neurophysiological changes as a potential reason for improved performance; their research suggests that warm-ups increase power production and performance by activating neuromuscular functions. Other researchers have cited this phenomenon as post-activation potentiation (PAP), which has been defined as the temporary increase in the contractile ability of muscles after a previous contraction session. One limitation of this study was the use of a small group of untrained, recreational, non-competitive runners instead of trained runners. Consequently, it becomes important not to generalize the findings to competitive runners. Yet, the results of this study may be more relevant for trained runners than recreational runners due, in part, to stringent training regimens, warm-up routines, and stretching protocols as well as potential differences in parameters such as height, weight, and BMI. Conversely, the findings from the present study may have value in generalizing to recreational runners commonly seen in physical therapy practice. Another limitation was soreness reported by the participants. Many of the participants complained of muscle soreness due to previous trials, and 10 participants cited muscular soreness as the reason for dropping out of the study. This may be related to the fact that the current subjects were recreational runners and therefore less accustomed to the higher muscular forces generated during sprinting than in other forms of running.

Future research should include the use of trained runners to see if these same effects are seen in these athletes as well. Further study might address the effects of stretching mode on return to sprinting activity among recreational runners, which is an important
consideration when taking patients through a full spectrum of rehabilitation and the resumption of prior activity levels. Research could also be conducted to see if there are any differences between sexes and use of multiple trials examining the effects over time in each condition should be considered.

CONCLUSIONS

The results of this study indicate that the NS condition was the only stretching condition in which statistically significantly improvements were found in acute or short-term measurements of sprint times in non-trained, recreational runners. The SS, BS, and DS stretching conditions did not affect acute measurements of sprint times. Although performed by all groups, the baseline 40-yard sprint may have been enough to facilitate performance enhancement, thereby improving the post NS condition sprint time. This suggests that 40-yard sprint performance may show greatest improvement without stretching and performance of a generalized “warm-up” task. These findings have clinically meaningful implications for untrained recreational runners who include IP stretching as a component of their warm-up, particularly prior to sprinting.

REFERENCES


ABSTRACT

Background/Purpose: Injury rates for softball players are similar to baseball players yet information regarding risk factors, pitching, and physical characteristics for high school windmill softball pitchers is limited. This information is needed to guide prevention, training, and rehabilitation efforts. The purpose of this study was to report descriptive data regarding the physical characteristics and pitching volume experienced by high school softball pitchers during one academic season. A secondary aim was to track and describe upper extremity injuries suffered by high school softball pitchers throughout the course of the 2009 season.

Methods: Twelve uninjured female softball pitchers (13-18y) from 5 Greenville, South Carolina high schools participated. Prior to the 2009 season, the pitchers' shoulder internal, external, total arc of rotation and horizontal adduction PROM was measured. During the 10-week season, aggregate pitch counts (pitch volume) and occurrence of upper extremity injury were tracked for each pitcher.

Results: Mean preseason internal, external, and total arc of rotation PROM was observed to be similar between the pitchers' dominant and non-dominant shoulders. The PROM measures of horizontal abduction (HA) appear to demonstrate a side-to-side difference with less HA on the dominant arm of the pitchers who were examined. Subjects threw in an average of 10.1 games (±4.9) during the season. Six pitchers threw in 60% or more of the team's games and 3 of 12 pitchers pitched less than 25% of games. Pitchers averaged 61.8 pitches per game (±31.5) and 745.8 (±506.4) per season. Pitch count data did not appear to be different between injured and non-injured pitchers.

Conclusions: Knowledge of pitch volume can be used to prepare windmill softball pitchers for the seasonal stresses, guide establishment of goals when recovering from injury, or assist in training for an upcoming season. Further research is needed to examine larger samples of pitchers over multiple seasons and years.

Level of Evidence: III

Key words: Pitch count, shoulder, softball

The authors would like to acknowledge the coaches, athletic trainers, parents and athletes of the Greenville County School system for their participation in and support of this study.
INTRODUCTION
Softball has continued to be a popular sport for high school athletes. In the past decade, participation at the high school level has grown by 16%.1,2 During the 2008-09 school year, girls' softball was the third most popular high school sport for girls.2 As participation has risen over the past decade, the number of players at risk for overuse injury has also increased.2 The overall incidence of injury, per 1000 athletic exposures (AEs), during an interscholastic season has ranged between 0.95 and 5.6 per 1,000 AEs for softball players.3-5 The upper extremity has been reported to be among the most commonly injured body regions in softball (40-52%).3,4,6,7 Shanley et al reported that the upper extremity was the most commonly injured body region for softball players with an overall rate of 2.9/1,000 AEs.3 Further, Rauh et al reported a 2- and 3-fold risk of shoulder and rotator cuff re-injury (an injury occurring after the initial injury to the same body location after recovery from the initial injury) in high school softball players.8 While the prevalence of overuse injuries has varied widely (30-85%) among softball athletes, these injuries have primarily been related to pitching and throwing in the field.9-11 Recently, Shanley et al. suggested that most high school softball shoulder injuries occurred early in the season and were related to an increase in game participation.9

In order to institute prevention strategies aimed at minimizing injuries in softball, a thorough understanding of the population at risk, participation level, incidence of injury, and risk factors for injury should be established. For baseball players, extrinsic factors including performance characteristics (pitching with pain or fatigue, pitch types, innings pitched, and pitch counts)12-14 have been suggested as contributors to non-contact baseball-related injuries. Intrinsic factors, such as, range of motion (ROM) deficits in internal rotation (IR) greater than 20° without concurrent increases in external rotation (ER) ROM combined with a reduction in side-to-side horizontal adduction (HA) have been associated with posterior shoulder tightness and are hypothesized to be pathological.15-19 Currently, few, if any, prospective studies are available on intrinsic or extrinsic risk factors risk factors for adolescent softball players, especially pitchers.20 Risk factors theorized to contribute to arm injuries among windmill softball pitchers include pitching with fatigue, decreased shoulder proprioception, posterior shoulder tightness, and innings pitched.21-23

In softball, participation is non-continuous and varies from outing to outing. For non-continuous sports, accounting for the actual number of plays is the more useful method of assessing risk as compared with the number of games played.24 Kerut et al reported that the number of pitches thrown was the risk factor most strongly correlated with pitching injuries among youth baseball players.24 They concluded that the overall number of pitches likely better accounted for the stresses placed on an athlete’s arm rather than merely tracking participation in games or innings. However, innings and games played have not been found to predict overall injury or the severity of injury for high school pitchers.14,22

The American Academy of Pediatrics Committee on Sports Medicine and Fitness has recommended restrictions on the number of pitches thrown in games, as well as instruction in throwing mechanics and training principles for both softball and baseball athletes.25 In 2007, Little League Baseball published regulations for game pitch counts and pitching rest days by age group.26 While these regulations became mandatory for baseball in 2010, no guidelines have been established for softball. The recommendations for baseball were based on three descriptive research reports from 2001-2006 indicating an association between injured youth (9-12 years) players and an increased number of pitches thrown as compared to healthy controls.14,27,28 Similar descriptive studies for high school softball pitchers are not available.

The associations between injuries, pitch count data, and innings played are not well documented. In a descriptive study of collegiate softball players, Loosli et al21 reported softball pitching injuries and categorized them according to mean innings pitched for each injury severity category. Specific pitch counts have not been associated with injury at the collegiate level. At the interscholastic competition level, the National Federation of State High School Associations has not recommended pitch count standards for high school softball or baseball.1 High school baseball pitch counts are regulated by each state, but pitch counts remain unregulated for high school softball.
To the knowledge of the authors, tracking of pitch counts has not been reported for high school aged softball pitchers. Thus, the objectives of this study were to 1) describe the pitch volume for high school windmill softball pitchers, 2) to describe the shoulder passive range of motion (PROM) of internal rotation, external rotation, and horizontal adduction for high school windmill softball pitchers, and 3) to describe and compare pitch counts for those athletes developing arm injuries versus those remaining uninjured throughout an interscholastic season.

METHODS
The study prospectively examined 12 female high school windmill softball pitchers in 5 Greenville, SC high schools during their 10-week season. Players between the ages of 13 and 18 were recruited to participate in the study. Subjects were excluded from the study if 1) they were being treated for a shoulder or elbow injury at the beginning of the season, or 2) unable to participate on the first day of practice because of upper extremity injury or soreness. The Rocky Mountain University of Health Professions Institutional Review Board approved the study. Parental consent and athlete assent were obtained.

Data Collection

Questionnaire. Prior to the 2009 spring interscholastic season, the pitchers completed a study questionnaire on baseline characteristics. Included were questions regarding years of playing experience, hand dominance, and history of prior injury (Appendix 1).

Shoulder Passive Range of Motion (PROM). Shoulder PROM of IR and ER were measured using a standard goniometer with a bubble level affixed to the stationary arm for dominant and non-dominant upper extremities. Subjects were placed in supine and their shoulders positioned in 90° of abduction. Measurements for IR and ER were performed in the plane of abduction and a small towel roll placed under the distal humerus was used to maintain the position of the humerus. A posterior force by the thenar eminence and thumb was then applied through the coracoid process to stabilize the scapula prior to the arm being rotated, and the humerus was passively positioned at the end of either IR or ER PROM with the force of gravity acting on the arm.

The goniometer stationary arm was placed along the midline of the lateral forearm and the axis of the goniometer was aligned with the olecranon. Two examiners performed all IR and ER measurements with one examiner providing stabilization force to maintain the shoulder position while the other examiner obtained the PROM measurement. The mean of 2 trials for was used for data analysis.

Shoulder Horizontal Adduction (HA) PROM. Shoulder HA PROM was measured in the supine position on the standard table with the scapula retracted and stabilized via examiner pressure with the thenar eminence contacting the lateral border of the scapula. The upper extremity was passively horizontally adducted across the body with the arm starting at 90 degrees of abduction in neutral rotation and the elbow flexed to 90 degrees. The angle between the humerus and the horizontal plane from the superior aspect of the shoulder was measured via goniometry, which has been described in the literature to be reliable and valid. Two measurements of HA PROM were performed and the mean calculated for each arm.

Pitch count. Over the course of the season, aggregate pitch counts and upper extremity injuries were tracked for each pitcher. A team coach collected pitch counts during each game for her pitcher. The pitch counts were recorded on the official game-scoring sheet. The primary investigator (ES) visited the school weekly to answer any questions and verify the previous week's pitch counts. All teams emailed weekly pitch counts per game to the primary investigator.

Injuries. Prior to the 2009 spring interscholastic season, participating athletic trainers were trained in the use of the Athletic Health Care System Daily Injury Report form. From the first official day of practice until the last regular or postseason competition, two parallel recording procedures, the Simtrak mobility system (Premier Software, Inc. Winfield, Illinois) and the Athletic Health Care System Daily Injury Report form, were used to track upper extremity injury incidence. An upper extremity injury was defined as any pitcher's shoulder or elbow muscle, joint, tendon, ligament, bone or nerve complaint reported by the player that occurred during any softball team sponsored game or practice during the season. All upper extremity injuries regardless of onset type,
gradual or immediate, and time loss were recorded and confirmed by the school’s athletic trainer.

**DATA ANALYSIS**
Means and standard deviations were calculated for all demographic data, range of motion variables, and pitch counts for softball pitchers. The number of subjects and injuries were too small to warrant tests of statistical comparison. All descriptive data was calculated using SPSS (SPSS for Windows, SPSS Science INC, Chicago, ILL).

**RESULTS**
At the beginning of the season, all pitchers (n = 12) were without injury and were capable of full participation in team activities. Two thirds of the pitchers reported playing an additional position in games during the season but denied participation as a catcher. Demographic data for the pitchers is presented in Table 1. Prior to the start of the season, 17% of the pitchers reported a previous upper extremity time loss injury. Preseason PROM variables are shown in Table 2. The PROM data for IR, ER, and total rotation seems to suggest similarity between the dominant and non-dominant shoulders. The HA PROM appears less similar, with an average side-to-side difference of 6.25° less on the dominant compared to the non-dominant arm.

Pitch count data for the softball players is presented in Table 3. On average, softball pitchers threw in 10.1 games (± 4.9) during the season. Six of the 12 pitchers threw in 60% or more of their games, and 25% (n=3) pitchers appeared in less than 25% of the team’s contests. Softball pitchers threw on average 4.3 innings per game and 14.9 pitches per inning. Game and seasonal pitch volumes averaged 61.8 (± 31.5), and 745.8 (± 506.4) respectively.

Only two (16.7%) of the pitchers incurred a shoulder injury during the 10-week season. Pitchers who sus-

---

**Table 1.** Characteristics of high school softball pitchers during the 2009 interscholastic softball season.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>15.2 (± 1.5)</td>
</tr>
<tr>
<td>Softball Playing Experience (yr)</td>
<td>7.7 (± 2.5)</td>
</tr>
<tr>
<td>Hand Dominance</td>
<td></td>
</tr>
<tr>
<td>% Right</td>
<td>92</td>
</tr>
<tr>
<td>Previous Time Loss Injury (%)</td>
<td>17</td>
</tr>
</tbody>
</table>

**Table 2.** Preseason shoulder passive range of motion (PROM) data for high school softball pitchers.

<table>
<thead>
<tr>
<th>Shoulder PROM Variable</th>
<th>Dominant</th>
<th>Non-Dominant</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Passive External Rotation (degrees)</td>
<td>12</td>
<td>119.1</td>
</tr>
<tr>
<td>Passive Internal Rotation (degrees)</td>
<td>12</td>
<td>60.6</td>
</tr>
<tr>
<td>Passive Total Rotation (degrees)</td>
<td>12</td>
<td>179.7</td>
</tr>
<tr>
<td>Passive Horizontal Adduction (degrees)</td>
<td>12</td>
<td>30.5</td>
</tr>
</tbody>
</table>

PROM= Passive range of motion, SD= Standard Deviation.
tained an upper extremity injury during the season had similar pre-season shoulder PROM compared to non-injured pitchers for dominant IR (59.8 ± 3.9 vs 60.8 ± 9.0), side-to-side IR loss (8.8 ± 13.1 vs 1.0 ± 7.3), and dominant total arc of motion (180.5 ± 18.4 vs 176.0 ± 5.6). In this small sample, the injured pitchers appeared on average to have less dominant HA than uninjured pitchers (20.3 ± 3.2 vs 32.6 ± 11.8) but appeared with to have similar non-dominant HA (34.5 ± 2.1 vs 37.2 ± 13.7). The mean pitch count per season for the injured pitchers (1170.5 ± 567.8) was higher than the non-injured pitchers (660.8 ± 479.0), yet examination of the standard deviations demonstrates clear overlap of pitch count between some athletes in each group. (Table 4). Mean game pitch totals for the injured and uninjured pitchers appeared similar (Table 4).

**DISCUSSION**

In efforts to minimize the occurrence of shoulder and elbow injury among baseball pitchers, several individuals and organizations have published recommendations for the modification of pitch volume in baseball.14,25-28 These recommendations have been directed toward game,14 season,14 and yearly pitch counts.20 Although the regulation of pitch counts among windmill softball players has been recommended,39 to the authors’ knowledge, actual pitch count limits for softball have not been established and high school softball rules do not address game or seasonal pitch counts.1 The current study's descriptive data documents PROM and pitch counts for high school windmill softball pitchers representing an initial phase in establishing safe guidelines for participation. While the mean pitch count was higher for injured pitchers than for uninjured pitchers, the standard deviations in each group seems to suggest that the pitch count totals could be similar between groups. The descriptive data from this study should be interpreted with caution based on the small sample size and number of injured pitchers.

**Shoulder PROM**

While shoulder PROM measures have been reported for high school softball players in general, the authors are unaware of data specifically describing pitchers therefore making comparisons difficult due to limited reports.20 The side-to-side shoulder PROM for IR and ER found in this study’s pitchers appear to differ from those reported in previous studies of high school20 and collegiate softball players.23,40 Specifically, no differences were found between the pitchers dominant

| Table 3. Means and standard deviations for pitch counts among high school pitchers. |
|------------------|-------|-------|
|                  | N    | Mean  |
| Total Pitches per Season | 12   | 745.8 |
| Total Pitches per Game   | 12   | 61.8  |
| Total Games Pitched     | 12   | 10.1  |

SD= Standard Deviation.

| Table 4. Pitch count means and standard deviations in injured versus non-injured high school softball pitchers. |
|------------------|-------|-------|-------|-------|
|                  | N    | Mean  | SD    | N    | Mean  | SD   |
| Total Pitches per Season | 2    | 1170.5| 567.8 | 10   | 660.8 | 479.0|
| Total Pitches per Game   | 2    | 78.3  | 20.1  | 10   | 58.2  | 33.3 |
| Total Games Pitched     | 2    | 14.5  | 3.5   | 10   | 9.4   | 4.6  |

SD= Standard Deviation.
and non-dominant shoulder PROM which contrasts with other reports documenting an altered total arc of PROM in softball players.\textsuperscript{20,23,40} The lack of agreement with prior reports may be partially related to the differences in the player position studied; the current study examined pitchers only whereas the other reports measured both pitchers and position players. As pitchers primarily use a windmill motion and position players exclusively use an overhead throwing motion, the differences in throwing mechanics may affect their shoulder rotational motion composition, thus accounting for the differences in ROM. The current methods should be replicated using a larger sample of softball pitchers in order to be able to compare to the results of this study.

Horizontal adduction PROM measures appear to demonstrate a side-to-side difference with less HA on the dominant arm of the studied pitchers. These results appear similar to the documented patterns of HA of other athletes.\textsuperscript{31,41,42} The similarity in the horizontal adduction measure may be associated with the comparable mechanics following ball release (cross body adduction, internal rotation, and pronation) between baseball and softball athletes. Further research is needed to investigate these results in a larger sample of pitchers.

**Average Pitch Count: Game**

Overall, the mean number of pitches thrown per game by a pitcher in the current sample was 61.8 ± 31.5, which is lower than those reported among collegiate softball players where an average of 90 pitches were thrown per game (range 60-141).\textsuperscript{43} Only 2 pitchers in the current sample averaged 90 or more pitches per game. Thus, the findings of the current study indicate that although these high school softball pitchers (14.9/inning) were throwing a similar number of pitches per inning (collegiate: 12.7/inning) they threw fewer innings and pitches per game with a resultant lower total volume than the collegiate softball pitchers.\textsuperscript{43}

**Injury by Average Pitch Count: Game**

While the injured softball pitchers demonstrated a pattern toward throwing more pitches per game on average than the non-injured softball pitchers no clear differences were observed. Only two of the 12 studied pitchers averaged 90 or more pitches per game. In comparison to prior reports, the injured pitchers in the current study averaged approximately 78.3 (± 20.1) pitches per game which was slightly lower than collegiate softball pitch counts among uninjured pitchers (mean: 90).\textsuperscript{43} The low number of injuries in the pitchers who threw more than 90 pitches per game may be partially related to the small number of pitchers that exceeded this average number of pitches.

**Average Pitch Count: Season**

In the current study, the softball players threw an average of 745 pitches and 2 pitchers threw more than 1500 pitches during their season. Werner et al. reported that adolescent windmill softball pitchers often throw more pitches during a weekend tournament (1200-1500 pitches) than the same age baseball pitchers throw in a season.\textsuperscript{23} However, the softball pitchers in the current cohort had lower total pitch volume over their 10 week season than Werner reported for those who participated in elite weekend softball tournaments.\textsuperscript{23}

**Injury by Average Pitch Count: Season**

The two injured softball players averaged almost 1200 pitches/season while the other 10 uninjured players’ averaged 660 pitches/season (approximately 55% less). While injured softball players threw more pitches on average per season than their uninjured counterparts examination of the standard deviations associated with these means demonstrates clear overlap of pitch count between athletes in each group and probably indicates a similar seasonal pitch count between groups. The small number of softball pitchers participating and few injuries sustained among the players in the current study limited the authors' ability to perform statistical analysis and further study is required in this area. To the authors' knowledge, game and seasonal pitch counts for high school softball pitchers (injured or non-injured) have not previously been reported. Two prior survey studies recorded the number of pitched innings reported by injured collegiate softball pitchers (82-93, mean = 88.3\textsuperscript{22} and 86-209, mean = 145).\textsuperscript{21} Axe et al.\textsuperscript{44} stated that collegiate softball pitchers averaged 12.7 pitches per inning. For comparative purposes, the injured softball pitchers would have thrown an average of 1,121 pitches per season in the cohort presented by
Hill et al.\textsuperscript{22} and 1,837 pitches in the Loosli survey\textsuperscript{21} if they averaged 12.7 pitches per inning (range 1041-2654). The injured high school softball pitchers in the current study threw a similar number of pitches per season as the number that would be attributed to the collegiate pitchers in the Hill study\textsuperscript{22} but fewer than those reported by Loosli et al.\textsuperscript{21}

**Strengths**

The overall prospective study design helped minimize several study biases. Recall bias and misclassification of injuries were minimized as trained health care professionals collected the data in a controlled, systematic, and prospective manner. The authors contacted coaches and athletic trainers on a weekly basis to verify injuries and pitch count data. Injury data were collected with parallel systems in order to increase the accuracy of such data. The subjects in this study were high school athletes that were supervised carefully during each game and throughout their season. The amount of exposure was consistently monitored throughout a short season. Additionally, the study was conducted over a relatively small geographical area, which allowed the researchers to control factors related to exposure (climate and competition level) and documentation of injury circumstances.

**Limitations**

Several limitations of the current study should be noted. The sample size was small, because each team had 1-2 softball pitchers that participated in most games. The relatively low incidence of injury in softball and the smaller sample size also limited the ability of the authors to perform statistical analysis and identify risk factors. The characteristics and practice patterns of the included high school softball teams may differ from those in other geographical regions limiting the generalizability of the findings. In this study sample, pitch types were not studied but may be important as a potential risk factor for injury as theorized by other researchers.\textsuperscript{12-14}

**CONCLUSION**

PROM data for IR, ER, and total rotation seem to suggest similarity between the dominant and non-dominant shoulders for windmill pitchers. Several authors have documented altered patterns of rotational ROM for softball position players.\textsuperscript{20,23,40} The average number of pitches per game and per season for the current sample of high school softball pitchers appeared similar to estimates of collegiate pitchers but less than elite pitchers described by Loosli in 1992.\textsuperscript{21} While mean counts per game and season tended to be higher for injured pitchers than non-injured pitchers, when examining the ranges and standard deviations it is possible that no differences between these groups existed. Several authors have documented a need for pitch counts to be documented and implemented in windmill softball.\textsuperscript{21,39,45} Differences in ball weight,\textsuperscript{46} pitching surface,\textsuperscript{46} biomechanics\textsuperscript{23,39,47,48} and field dimensions\textsuperscript{46} make it difficult to justify and questionable to use established baseball pitching guidelines. Baseline descriptive data are needed to establish tolerance and response to the windmill pitching motion. Recommendations for pitch count limitations, preseason/in-season conditioning, and performance enhancement programs should only be recommended after norms are established. Future studies with larger sample sizes are recommended to continue examining pitch count and also examine variations in pitch type as potential risk factors for upper extremity injury risk in high school softball players.

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APPENDIX

Preseason Questionnaire
HS softball & baseball

Please answer the following questions as completely as possible. If you have any questions, a researcher would be happy to answer it for you.

Study number:

What is your Gender? ☐ female ☐ male

What is your age?

What grade are you in? ☐ 9th ☐ 10th ☐ 11th ☐ 12th

What high school do you attend?

What organized sports do you play? ☐ Baseball ☐ Softball ☐ others________________________

How long have you played these sports? (in years)

Which arm do you primarily throw with? ☐ left ☐ right

Which arm do you bat with? ☐ left ☐ right ☐ switch

Do you have pain in either arm at rest or with any activity now or within the last 6 months?

Now? ☐ no ☐ yes

If yes, which arm? ☐ left ☐ right

Last 6 months? ☐ no ☐ yes

If yes, which arm? ☐ left ☐ right

Have you ever had an injury to your arms that has caused you to miss a practice or game?

☐ no ☐ yes

if yes, please explain:

<table>
<thead>
<tr>
<th>Side of Injury</th>
<th>Body Part (example: elbow; shoulder)</th>
<th>Type of Injury</th>
<th>Position Played (when injured)</th>
<th>Month/ Year of Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

What position do you play? (Check all that apply) ☐ catcher ☐ infield ☐ outfield ☐ pitcher

What position do you play most often? (Choose one) ☐ catcher ☐ infield ☐ outfield ☐ pitcher

Did you participate in any specialty stretching or strengthening program this offseason?

☐ no ☐ yes

if yes, please explain/describe:

Did you perform this stretch within the last 24 hours?

☐ no ☐ yes
ABSTRACT

Acromioclavicular injuries are quite common and approaches to early management of those that are described as a Type III are controversial. The Rockwood Type III classification implies complete disruption of the acromioclavicular and coracoclavicular ligaments, resulting in inferior positioning of the scapula and, thus, the glenohumeral complex while the clavicle appears more superiorly prominent. Clinical management can include surgical or conservative techniques. This case report outlines the decision making process related to this type of injury, as applied in the diagnosis and management of 61 year-old recreational athlete.

**Level of Evidence:** 5 (Single Case report)

**Key words:** Acromioclavicular injury, functional outcomes, shoulder separation, Type III management

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INTRODUCTION
The acromioclavicular (AC) joint is a diarthroidial joint, which includes a fibrocartilaginous disc linking the distal lateral end of the clavicle to the medial edge of the acromion process. There is significant variation of the joint articular size, shape, orientation, and mobility. The composition of the articular cartilage changes during the second decade of life resulting in a more fibrocartilaginous matrix. Likewise, the intra-articular fibrocartilaginous disc degenerates during aging and is no longer a functional structure by age 40. The ligamentous structures that control the joint are the acromioclavicular ligament (primarily controlling anterior/posterior motion) and the coracoclavicular ligaments, comprised of the conoid and trapezoid ligaments (primarily maintaining the vertical position/spacing of the clavicle to the coracoids) (Figure 1). Discussion of disruption of the controlling ligaments dates back to the writings of Hippocrates where he proposed that no significant “impairment” results from these injuries. In many ways, little has changed in the ensuing 2400 years. There are now several well-conducted studies that demonstrate equality of outcome in most subjects when comparing “benign neglect” to nearly all techniques of immobilization or surgical interventions.

Figure 1. Bony and ligamentous anatomy of the acromioclavicular joint.

Rockwood provides a classic chapter on these injuries in The Shoulder. As initially published in 1990, Rockwood suggested a primary classification scheme that delineates severity of injury in relation to specific structure. Type I injury is a partial tearing of the acromioclavicular ligament but with the joint remaining intact. Type II injury is a complete disruption of the acromioclavicular ligament while the coracoclavicular ligaments are not completely disrupted. Type III injury results in greater movement of the described segments (a dislocation) as the acromioclavicular and coracoclavicular ligaments are both completely disrupted and a visible alteration of the shoulder complex results. This greater anatomical disruption results in the “separation” of the clavicle from the coracoid and the clavicle appears superiorly positioned with significant increase in clavicle motion in all planes. Rockwood then further delineated special variations of the Type III as IV, V, and VI where the clavicle is captured by other soft tissues. He outlined recommended treatment based on classification. The focus of this case report is on the management of classic Type III injury.

CLINICAL PRESENTATION
A right hand dominant 61 year-old male faculty member was playing doubles tennis. During play, he was moving to his right in an attempt to extend for a forehand when his shoes caught an edge causing him to fall to the court surface. His right shoulder impacted the surface as he attempted to roll but sustained significant impact prior to completing the roll. Although he played two additional points, he was unable to elevate the shoulder in order to perform a serving motion. The subject had sustained a second-degree acromioclavicular injury four decades prior. Subsequent to the reinjury sustained during tennis, he was able to palpate the freely positioned clavicle, which exhibited easy ballottement, consistent with a Grade III injury, and not a IV, V or VI. As the shoulder was exquisitely painful, ice was applied throughout the night and the subject attempted to sleep in a recliner with the arm supported via pillow propping. The next morning he went to an orthopaedic walk-in clinic in order to have a radiographic assessment to rule out possible fracture. Initially, he was using a typical sling which was readily available, in order to minimize discomfort that was present in
the standing position (Figure 2). His presentation was classic for an AC joint injury, with obvious loss of normal contour and significant descent of the glenohumeral complex making the clavicle appear significantly elevated (Figure 3).

New residents and fellows staffed the orthopaedic clinic that the subject utilized for radiographic studies. The immediate discussion offered by the resident there was to utilize magnetic resonance imaging (MRI) to better delineate the soft tissue involvement. The subject (a physical therapist with 30+ years of experience) questioned how this delineation might impact the actual management. The resident physician stated that it would determine if surgery would be performed. The subject then asked why surgery would be performed for this diagnosis if the plain radiographs did not show a fracture and that the free ballottement of the clavicle obviously indicated a Rockwood Grade III injury. After consultation with the attending physician, a standard radiographic series was obtained. The radiographs are presented as Figures 5, 6, and 7.

At this point, the attending physician agreed that there was no need to do a weighted view to enable comparison to the left as he was relatively certain that the injury was well described as a Rockwood Grade III. A relatively short discussion ensued regarding management options. This discussion included the
newest surgical options being designed to truly reconstruct the coracoclavicular ligaments in as anatomically correct fashion as possible. The following is a synopsis of the literature related to surgical approaches to the Type III acromioclavicular separation.

Early approaches were designed to hold the clavicle in proper alignment with the acromion using screws, wires, or pins to provide fixation. Because of problems with wires breaking and migrating, surgeons moved to Steinmann pins which may still break and migrate, thus, being problematic. Because of these complications seen with wires and pins, surgeons changed to utilization of screws of many varieties to stabilize the clavicle in a temporary fashion. The use of screw fixation was later advanced to clavicular–coracoid placement using a large headed lag screw designed by Bosworth (Figure 8). Other surgeons used a distal hooked-plate to stabilize the joint proper (Figure 9). Typically, the screw or plate was inserted to provide temporary fixation and removed at a later date.

Figure 6. Axillary view radiograph of the subject's right shoulder, used to examine the positional relationship of the humeral head and glenoid fossa, which was intact in this case.

Figure 7. This modified lateral view radiograph was completed because of the subject's intolerance (due to pain) of alternate positioning requested by the radiological technician.

Figure 8. Example of a Bosworth screw stabilizing the clavicle-coracoid distance (not in the subject of this case report).

Figure 9. Example of Hook-plate stabilization (not in the subject of this case report).
Surgeons later progressed to loops of material (including wire and Dacron®) around the clavicle and coracoid in order to create a restraint to displacement.\textsuperscript{10,11} Unfortunately, using looped materials led to erosion into the bony structures where they resided, resulting from the normal rotational clavicular movements that still occurred. Difficulties encountered with looped materials pushed surgeons to minimize the use of looped materials and design a technique that did not create the aforementioned complications. In 1972, Weaver and Dunn published their procedure which included distal clavicle resection and transferring the acromial insertion of the coracoacromial ligament to the distal clavicle.\textsuperscript{12} In the more recent past, focus has shifted to surgery designed to restore anatomic normalcy to the greatest extent possible. The anatomy related to reconstruction was defined well by Rios et al\textsuperscript{13} and Salzmann et al.\textsuperscript{14} Likewise, the surgical considerations related to anatomy were defined by Coale et al,\textsuperscript{15} while Beitzel et al\textsuperscript{16} examined the biomechanics of the newest repair techniques. This has led to the use of an endobutton placed in the clavicle in order to better duplicate the desired insertions of the conoid and/or trapezoid ligaments.\textsuperscript{17} Today, if surgical repair or reconstruction is performed, surgeons attempt to duplicate anatomy and enable normal relationships to be recreated.

Interestingly, during the past 20 years numerous studies have been completed which examined the outcomes after these surgeries when compared to conservative care. An early report by Taft et al\textsuperscript{6} in 1987 showed that in 127 subjects (52 surgical and 75 conservative) with an approximate 10-year follow-up period, that the “clinical (subjective and objective) ratings were equal in the two groups.” In 1989, Bannister et al\textsuperscript{3} published a randomized control trial of the management of acute acromioclavicular dislocation. Sixty patients were randomly assigned to receive screw fixation or sling immobilization (27 and 33, respectively). Results were equal between groups four years post-operatively. Further, the surgeons reported that non-operative treatment was superior in the early timeframes. Consistent with these early reports, Schlegel et al\textsuperscript{5} provided the natural history of untreated patients with third degree acromioclavicular injury. The average return to work was nine days, objective findings were “surprisingly good considering that no formal treatment was given for this injury” with only a decrease in the strength of the bench press demonstrable, and concluded “that a majority of patients will do well without any formal treatment.”\textsuperscript{5, p. 702} Smith et al concluded in their recent meta-analysis: “based on the current evidence base, operative management of grade III acromioclavicular dislocations results in better cosmetic outcome (p<0.0001) but a greater duration of sick leave (p<0.001) compared to non-operative management. There was no difference between the two interventions in terms of strength, pain and throwing ability (p >0.05).”\textsuperscript{18, p. 26} Kim et al\textsuperscript{3} outlined the recommended imaging studies to be performed during assessment of these injuries and reiterated that plain film imaging is the expected and most appropriate starting point.

**CASE MANAGEMENT**

As the patient was a 61 year-old physical therapy faculty member and recreational athlete, with a remote history of a grade II right acromioclavicular joint injury, the discussion of surgical intervention was questioned. Although significant separation was evident (Figures 3 and 5), significant arthritic change was already present at the acromioclavicular joint. The literature does not support early repair being any better than later reconstruction, if it were determined that the resultant instability was problematic and, thus, requiring surgical fixation long-term. The patient was provided a sling that was supportive and provided enhanced fixation of the forearm to the trunk (Figure 10) and was offered analgesic medications.
The subject was urged to wear the sling as much as possible but could remove it to shower and it was recommended that he support the arm when out of the sling for comfort (as shown in Figure 4). The initial estimate was that two weeks of sling use would be required and that the subject would need to experiment to determine the best sleeping positions. He was to apply ice as often as possible with the recommendation being 20 minute treatments. If after a few weeks he was not happy, he was to contact the surgeon for a follow-up discussion. Otherwise, he was to determine his rehabilitation course. For clinicians not familiar with recommended rehabilitative approaches to the treatment of all grades of acromioclavicular injuries, an excellent resource has been compiled by Reid et al.19

Physical therapy friends offered multiple interventions. The most common recommendation was to tape the clavicle downward. However, since the coracoclavicular ligaments were completely torn in this Grade III presentation, the use of tape would be palliative at best and in the authors' experience – not well tolerated, as it is frequently irritating to the skin. In this particular circumstance this intervention may have been less than useful as the AC joint already demonstrated arthritic changes and might not tolerate the additional external pressure. It was also very interesting that the clavicle could be reduced to the acromion via humeral compression and inferior pressure to the clavicle – but the reduction was lost as soon as either was removed. Some older physical therapists suggested the use of the vest/humerus sling, commonly known as the Kenny Howard Sling. This device attempted to keep the humerus pulled up and the clavicle pushed downward. Of course, a problem occurs when the subject must bathe, during which, removal of this type or any type of sling results in loss of joint approximation. History has shown that patients had very poor compliance in using the Kenny Howard Sling and the treatment was, in reality, benign neglect.

The subject found that sleeping in a recliner offered the most flexibility in pillow propping and maintenance of a comfortable, supported position. He also found that it was easier to initiate hip flexion/standing postures from the recliner than a supine bed position. The subject is right hand dominant, and the functional alteration of typing with the left greatly impacted his work comfort. On the third day post-injury, he found a propping position that enabled use of the right hand for typing but soon realized that he should not lean onto the supported right forearm as clavicle would impact the acromion with resultant discomfort. The sling was used for one week and careful movements of the humerus below 90 degrees were begun. Figure 11 shows the presentation at one week post injury. At this point, the subject began sleeping in a bed and wore a more encompassing sling or a pillow was placed to support the forearm in relation to the trunk. He was performing scapular control motions on an hourly basis to not allow a decrease in proximal muscular control.

During the next three weeks, a slow progression of activities ensued. Toileting was one self-care activity that remained difficult as extension and internal rotation combined to give an impingement like response. Side arm sleeping (both onto the involved side and also prone with the involved shoulder elevated to enable the forearm to be under the pillow) was accomplished during the third week along with full range of motion. However, tenderness in full elevation as well as the combined movements of internal rotation and extension remained. He was able to work as a volunteer framer for a Habitat for Humanity home starting in the third week and could do all tasks below 90 degrees, but was cautious to limit overhead nailing or lifting of heavy objects. He was able to swing a golf club without discomfort during the fifth week. Although a very obvious “step-off” deformity remains, only minor popping or irritation

Figure 11. Obvious ecchymosis to the area overlying the coracoid process, 1 week post injury.
seems to persist. The shoulder complex does ache periodically, particularly after several hours of typing or several hours of heavier upper extremity work as a framer have been completed.

CONCLUSIONS
Although the treatment of Rockwood Type III may be somewhat controversial, the predominant literature is supportive of non-operative management. If the patient is not satisfied with their function and/or cosmesis after 3–6 months, surgical reconstruction can be performed with more recent approaches focused on anatomic restoration. In this patient, early immobilization for comfort, early functional activities limited to below 90 degrees followed by functional patterns in the third week accomplished a rapid return to full range of motion and activity. Plain film imaging is all that may be required in the majority of these injuries to delineate grade or type of injury and guide treatment.

REFERENCES
ABSTRACT

Purpose/Background: Medial shin pain (MSP) is a common complaint that may stop an athlete from running. No previous study has identified deficits in pelvic, hip or knee motion as potential contributing factors to MSP. The purpose of this study was to investigate the differences in kinematics during running between uninjured athletes and those with MSP. Secondary analyses investigated differences in limbs between groups and differences between sexes.

Methods: This case-control study investigated fourteen runners aged 18-40 years old with a history of unilateral MSP and fourteen runner controls. Three dimensional lower quarter kinematics were captured as runners ran on a treadmill. Specifically, peak hip internal rotation (IR), frontal plane pelvic tilt (PT) excursion, and knee flexion were examined.

Results: Groups were similar in age, mass, height, and training mileage. Subjects with a history of MSP demonstrated significantly greater frontal plane PT (P = 0.002, Effect size = 0.55) and peak hip IR (P = 0.004, Effect size = 0.51); and less knee flexion (P = 0.02, Effect size = 0.46) than the control group. No significant difference was found in kinematics of the MSP group during their involved side stance phase as compared to their non-involved side.

Conclusions: Runners with MSP displayed greater PT excursion, peak hip IR, and decreased knee flexion while running as compared to a control group. These results should help guide treatment for the running athlete that experiences MSP.

Level of Evidence: 3b

Key Words: Exercise related leg pain, running, overuse injuries, shin splints
INTRODUCTION

Over 38 million Americans choose running as their mode of exercise. Athletes that participate in running sports are commonly seen by a sports medicine specialist for overuse injuries involving the lower extremity.¹ Medial shin pain (MSP) describes a specific overuse injury which produces pain along the posteromedial aspect of the distal two-thirds of the tibia. For purposes of this study, it excludes diagnoses of stress fracture or posterior compartment syndrome.¹,² The sports in which athletes are most commonly afflicted are cross-country, track, basketball, and volleyball. The incidence of MSP in long distance runners can be as high as 16.8% and is more prevalent in female runners.³ In the military, the incidence has been reported to be as high as 35% with females being injured more commonly than males.³,⁴ Several risk factors have been suggested in the literature as causative of MSP.²,⁵,⁶ These factors are diverse and some are contradictory. These factors can be divided into three subsets of etiology including pathomechanics, training error, and body mass. The most widely studied subset is pathomechanics. Examples of all factors include pes cavus,⁷ pes planus,⁶ pronation velocity,¹ time to maximum pronation,⁸ prolonged rearfoot pronation,⁸ limited ankle motion,² sex,⁵ bone mineral density,⁹ menstrual dysfunction, previous injury¹⁰,¹¹ and increased impact forces while running.¹² Of all these factors, the only factor that is consistently linked to MSP is a previous injury.

Faulty biomechanics can be very detrimental to the running athlete when they result in pain. Biomechanics in the lower extremity hinge on the principle of the kinematic chain. The kinematic chain is composed of successively linked joint segments. Each segment transfers forces and motions to the neighboring joints in a predictable pattern.¹³ Therefore, in theory, when dysfunction occurs at a specific joint, the dysfunction will transfer to the following joint in sequence. For example, when decreased motion occurs at the ankle during weight-bearing activity, both the knee and hip will feel the effects of the dysfunction and attempt to balance out the lost motion by increasing their ranges of motion. Attempts to compensate for the faulty mechanics of the ankle will cause the knee and hip to function in a new pattern. This transfer of faulty forces and movement can lead to injuries. This principle holds true for any joint in the chain during weight-bearing; therefore pelvic and hip range of motion are possible contributors to injury in the lower extremity. Research on the biomechanical relationship of the pelvis and hip with respect to their influence on MSP is scarce to non-existent.

Specific to running and MSP, proximal mechanical faults will affect lower limb loading which may cause tissue breakdown.¹⁴ For example, if the stance limb femur internally rotates more than it should and the knee lands in limited flexion then the forces on the distal limb may be increased.¹⁵

Therefore, the primary purpose of this study was to investigate the differences in kinematics during running between uninjured athletes and those with a history of MSP. Secondary analyses investigated differences in limbs between groups and differences in females and males. The authors hypothesized that the MSP group would display more frontal plane pelvic tilt (PT) excursion and hip IR as compared to the control group. Determining the presence of specific hip impairments or faulty hip to lumbo-pelvic motion in athletes with lower leg pain could guide future research to determine the possible cause/s of these factors (e.g. muscle weakness, range of motion deficits, muscle timing).

METHODS

Subjects

Fourteen runners (8 females, 6 males) with a history of unilateral MSP and fourteen runner controls (8 females, 6 males) were recruited. The group with a history of MSP was recruited first, and then the control group was recruited to match the MSP group for age, sex, and training mileage. Groups were similar in age, mass, height, and training mileage (Table 1).

In order to participate in the study the subjects needed to be avid runners that ran at least 10 miles/week for the last six months or more. Inclusion criteria were 1) 18 to 40 years of age, 2) A history of medial shin pain in one lower extremity above the ankle that occurred with running and caused the runner to stop running, 3) Presently not experiencing pain greater than 1/10 with running so as not to interfere with running kinematics, 4) Duration of symptoms greater than four weeks, but not greater than one year and occurring within the last two years.
Subjects were excluded from the study if they 1) Had a history of a lower extremity stress fracture, compartment syndrome, distal nerve pain, 2) Recent (within one year) history of trauma or surgery to the lower extremity, 3) Knee pathology/surgery, 4) Parasthesia in the lower leg, 5) Presented with excessive anteversion or retroversion as measured by the Craig’s test, 6) Presently complained of low back pain, and 7) Had a history of hip or knee pain. Subjects were not excluded if they had received physical therapy for their medial shin pain. Individuals with anteversion/retroversion were excluded as the authors felt that this structural deviation would influence normal hip kinematics. Additionally, subjects were excluded if they had a neurological condition or cognitive or psychological disorder that might interfere with the testing. The screening process was two-staged. Initially a phone interview was conducted to screen for age, weekly mileage, injury location, present symptoms, and injury history. Once subjects passed the phone screen, they were invited to visit the testing laboratory where they were further screened for exact injury location and to rule-out any other exclusion criteria. The second screening was performed by an athletic trainer/physical therapist with over twenty-five years of sports medicine experience. The screening included palpation for location of symptoms, sensation testing, hip, knee, and ankle clearing, and a tibial percussion test. Besides the 14 runners that were included in the MSP group, five runners were excluded after the initial phone interview for not meeting study inclusion criteria. No runners were excluded once they were invited for the laboratory visit.

### Experimental protocol

Ethical approval for this study was approved by the University of Kansas Medical Center's Internal Review Board. All subjects consented prior to the beginning of the study.

**Preliminary Tests:** The physical examination included measures of height, weight and the Craig test. The Craig test was performed\(^\text{16}\) to determine if subjects had a normal, anteverted or retroverted hip. For the Craig’s test, subjects were placed in prone with the knee flexed to 90 degrees. The clinician palpated the greater trochanter of the subject and then passively rotated the limb until the tip of the trochanter was most prominent laterally. The angle that the limb measured relative to the vertical is the degree of anteversion. An angle less than 8 degrees is retroverted and an angle greater than 15 degrees is anteverted.\(^\text{16}\) Intra-tester reliability is high for the Craig test and is reported in the literature to range from 0.80–0.90.\(^\text{17,18}\)

**Hip kinematics during running:** To acquire kinematic analysis of the pelvis, hip and knee during treadmill running, a six camera passive marker system (Vicon, Oxford Metrics LTD, Oxford, United Kingdom) at a sampling frequency of 250 Hz was used. Reflective markers (14 mm spheres) were placed bilaterally over the following anatomical landmarks: anterior superior iliac spine (ASIS), posterior iliac spine, lateral thigh, lateral shank, 2nd metatarsal heads, lateral malleoli, posterior calcaneus. The marker placement was based on the Plug-in Gait model (Oxford Metrics LTD, Oxford, United Kingdom) and depicted in Figure 1. The markers were held in place with double sided adhesive tape.

### Table 1. Subject demographics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>MSP</th>
<th>Control</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>29.2 ± 5.96</td>
<td>26.5 ± 5.39</td>
<td>0.22</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>69.6 ± 15.04</td>
<td>68.39 ± 11.82</td>
<td>0.95</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>172.96 ± 10.15</td>
<td>171.27 ± 9.08</td>
<td>0.65</td>
</tr>
<tr>
<td>T-mill speed (mph)</td>
<td>6.91 ± 0.85</td>
<td>6.79 ± 0.81</td>
<td>0.42</td>
</tr>
<tr>
<td>Training miles</td>
<td>21.07 ± 16.42</td>
<td>17.29 ± 13.96</td>
<td>0.52</td>
</tr>
</tbody>
</table>

MSP = medial shin pain
All subjects wore their self-selected running shoes and were allowed to wear the orthotics that they normally wore with running. Prior to running, a standing calibration trial was performed to establish segment lengths, joint centers and joint coordinate systems. The subjects were asked to run on a treadmill (Life Fitness, Schiller Park, IL, USA) at a zero percent grade. Subjects were instructed to run at a speed comparable to their five kilometer pace. Subjects completed a short warm up which consisted of walking for five minutes at 4.83 km/h followed by jogging for three to five minutes and then running at their self-selected test speed for five minutes. Five trials of five seconds of data were collected for each subject at 2.5 minutes into the self-selected speed trials.

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Statistics
Group demographics were compared for age, mass, height, training miles, and testing treadmill speed using independent t-tests. Independent t-tests were calculated between extremities in the MSP and control groups for the variables PT excursion, peak hip IR and peak knee flexion. Independent t-tests were calculated between the involved limb of the MSP group and a randomly selected limb of the control group for the same variables. Level of significance was
established at 0.05. Effect size was computed for differences between limbs in the MSP and control groups. A small effect is considered for values that are greater than or equal to 0.2 and less than 0.5, a moderate effect is greater than or equal to 0.5 and less than 0.8, and a large effect size is a value greater than 0.8. Secondary analyses were performed on the two limbs for females and males for each of the two groups. All statistical analyses were performed using SPSS, Version 17.0 (SPSS Inc, Chicago, IL, USA).

RESULTS
There were no differences in age, body mass, height, mileage run per week, or testing treadmill speed between groups (Table 1). Subjects in both groups displayed no significant difference between limbs with regards to the three variables studied (Table 2 and 3). Subjects with a history of MSP demonstrated significantly greater frontal plane PT (P = 0.002, Effect size = 0.55) and peak hip IR (P = 0.004, Effect size = 0.51); and less knee flexion (P = 0.02, Effect size = 0.46) than the control group (Table 4).

The variable data for females were compared to the data for males within each of the two groups. In the MSP group females had significantly greater PT compared to the males when analyzing the involved limb (P = 0.04). This difference was not seen on the uninvolved limb (Table 2). In the control group, no significant difference was found between females and males for either limb using the same variables.

DISCUSSION
The primary purpose of this study was to determine the relationship between select lower extremity kinematics and a history of MSP in the running athlete. Beyond the research regarding athletes with a diagnosis of tibial stress fracture, no previous study has investigated whether or not such a relationship exists. First, it is necessary to recognize that MSP, much like other musculoskeletal dysfunctions, can have multiple and various etiologies. The inclusion/exclusion criteria used for the current study, as well as clinical screening, attempted to limit the variability of etiology. The majority of the subjects had complaints that were consistent with medial tibial stress syndrome, but the authors did not use this term because there are no agreed diagnostic criteria for medial tibial stress syndrome. Still, it must be recognized that the subjects in the current study most likely were not a completely homogeneous group.

Differences between limbs: In the current study, the authors examined individuals with a history of unilateral shin pain in order to ascertain if there was a limb difference in runners with a history of MSP. These

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Table 2. Kinematic values for the two limbs in the MSP group. All values are in degrees reported as means ± standard deviation.

<table>
<thead>
<tr>
<th>Motion</th>
<th>Involved</th>
<th>Uninvolved</th>
<th>P value Between involved/uninvolved</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F N = 8</td>
<td>M N = 6</td>
<td>P*</td>
</tr>
<tr>
<td>PT</td>
<td>9.55 ± 1.8</td>
<td>7.25 ± 1.9</td>
<td>0.044*</td>
</tr>
<tr>
<td>HIR</td>
<td>9.65 ± 3.4</td>
<td>13.91 ± 6.4</td>
<td>0.132</td>
</tr>
<tr>
<td>KFL</td>
<td>37.19 ± 6.6</td>
<td>37.01 ± 4.0</td>
<td>0.954</td>
</tr>
</tbody>
</table>

MSP = Medial Shin Pain
PT = Pelvic Tilt (frontal plane)
HIR = Hip Internal Rotation
KFL = Knee Flexion
F = Females
M = Males
T = Total
P* = p value between male and female group
* = statistically significant at p ≤ 0.05
results are displayed in Table 2. Within the MSP group, none of the three variables that were measured were statistically different from the involved to the uninvolved limb. No differences were found between limbs in the control group (Table 3).

Symmetry of the lower extremity is expected in sports such as running that involves primarily sagittal plane and reciprocal movement between extremities. Shin pain is commonly bilateral and for this population with unilateral pain, limb asymmetry with regards to PT, hip IR, and knee flexion was not statistically different. Presently, to the authors’ knowledge, no study has examined the same kinematic variables and differences between limbs in runners with a history of MSP. A study performed by Zifchock et al investigated side-to-side differences of kinetic and kinematic variable in overuse running injuries in twenty runners.21 These researchers found a significant difference in total passive IR motion between groups, with the injured runners having more total IR.21 Although, the measure was passive there is some suggestion that increased passive IR is associated with increased dynamic IR22 while others would state the contrary opinion, that static measures do not correlate with dynamic measures.23

### Table 3. Kinematic values for the two limbs in the Control group. All values are in degrees reported as means ± standard deviation.

<table>
<thead>
<tr>
<th>Motion</th>
<th>Designated Involved</th>
<th>Designated Uninvolved</th>
<th>P value Between involved/uninvolved</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F N = 8 M N = 6</td>
<td>T N = 14</td>
<td></td>
</tr>
<tr>
<td>PT</td>
<td>6.34 ± 2.3</td>
<td>5.11 ± 1.2</td>
<td>0.231</td>
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<tr>
<td></td>
<td></td>
<td>5.76 ± 1.9</td>
<td></td>
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<td></td>
<td></td>
<td>5.89 ± 1.6</td>
<td>0.095</td>
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<td></td>
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<td>4.89 ± 1.0</td>
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<td></td>
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<td>5.24 ± 1.6</td>
<td>0.665</td>
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<td>0.403</td>
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<td></td>
<td></td>
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<td>0.158</td>
</tr>
<tr>
<td>HIR</td>
<td>6.91 ± 3.6</td>
<td>5.38 ± 3.3</td>
<td>0.221</td>
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<tr>
<td></td>
<td></td>
<td>6.26 ± 3.5</td>
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<td></td>
<td></td>
<td>10.1 ± 2.7</td>
<td>0.424</td>
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<td>7.63 ± 8.0</td>
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<td></td>
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<td>0.107</td>
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<tr>
<td>KFL</td>
<td>42.07 ± 5.4</td>
<td>43.58 ± 5.9</td>
<td>0.629</td>
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<tr>
<td></td>
<td></td>
<td>42.12 ± 4.8</td>
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<td></td>
<td></td>
<td>40.56 ± 5.1</td>
<td>0.501</td>
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<td></td>
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<td>42.74 ± 5.8</td>
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<td>0.537</td>
</tr>
</tbody>
</table>

PT = Pelvic Tilt (frontal plane)
HIR = Hip Internal Rotation
KFL = Knee Flexion
F = Females
M = Males
T = Total
p* = p value between male and female group
* = statistically significant at p ≤ 0.05

### Table 4. Kinematic values for the two groups. All values are in degrees reported as means ± standard deviation.

<table>
<thead>
<tr>
<th>Motion</th>
<th>MSP N = 14</th>
<th>Control N = 14</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT</td>
<td>8.56 ± 2.2</td>
<td>5.86 ± 1.9</td>
<td>0.002a</td>
</tr>
<tr>
<td>HIR</td>
<td>11.48 ± 5.2</td>
<td>6.25 ± 3.5</td>
<td>0.004a</td>
</tr>
<tr>
<td>KFL</td>
<td>37.11 ± 5.4</td>
<td>42.12 ± 4.8</td>
<td>0.02a</td>
</tr>
</tbody>
</table>

MSP = medial shin pain
PT = Pelvic Tilt (frontal plane)
HIR = Hip Internal Rotation
KFL = Knee Flexion
* = statistically significant at p ≤ 0.05
Difference between groups: In comparing the MSP to the control group, statistically significant differences were observed for the variables PT, peak hip IR, and knee flexion (Table 4). The retrospective nature of the study design does not allow the authors to ascertain if the differences that were seen are due to the MSP or a result of the MSP. It can only be stated that there was a difference between groups.

In the current study, the subjects ran at an average speed of 3.08 meters/second, with the amount of PT being significantly greater (P = 0.002) for the involved limb of the MSP group (8.56 degrees) as compared to the average of 5.86 degrees for the control group. The IR value was less for the control group (6.25 degrees) and greater in the MSP group (11.48 degrees), a difference that was significantly different between groups (P = .004). The ROM values for IR varies in the literature from 8–10 degrees. Differences found in the current study compared to the Schache et al study are probably due to differences in running speed where runners in the current study averaged a slower running speed. Related to knee flexion, the MSP group averaged 37.11 degrees of flexion at foot contact whereas the control group had greater knee flexion at contact (42.12 degrees) and this difference was statistically different (P = 0.02). Differences between groups were relatively small: 2.70 degrees for PT, 5.23 degrees for peak hip IR, and 5.01 degrees for knee flexion. The moderate effect sizes associated with these differences support the results of the statistical analyzes. However, it is not clear if these values are clinically significant.

During running, each foot strikes the ground approximately 600 times per kilometer. With each heel-strike forces are transmitted from the foot up the lower extremity to the lumbar spine. Even minor malalignments and/or abnormal movement patterns can accumulate, resulting in an overuse injury. A greater amount of motion at the pelvis and hip would suggest a lack of stability in those joints in the selected planes of hypermobility. The authors theorize that excessive pelvic drop and hip rotation results in compensation distally that contributes to the development of MSP. The concept of proximal hip contributing to distal lower extremity pathology is further detailed in a conceptual model that is displayed in Figure 2. Increased frontal plane PT has been described to create a knee valgus moment at the knee as a result of the body’s center of mass shifting medially. This increased valgus moment at the knee may result in compensation distally of increased subtalar joint pronation. In addition the MSP group had less knee flexion during stance which may affect the load dissipation of the ground reaction forces. Knee flexion during the initial phases of running gait is a key component for shock absorption throughout the lower quarter, without which the shock will be attenuated through the tibia and/or soft tissue.

Although there are not many investigations available for comparison with the current results, previous investigators have theorized regarding the biomechanical variables assessed in the current study. Hip IR, knee abduction and rearfoot eversion has been found to be associated with injuries in runners.
Increased levels of hip IR have been previously found in runners with tibial stress fractures. Although the subjects in the current study did not have tibial stress fracture, shin pain is a precursor for tibial stress fracture. Hip motion does influence the way the foot hits the ground, stressing either the soft tissue or bone in the lower limb. In the current study, the three kinematic variables were examined independently, however, it is likely that these factors are inter-related and may combine to increase injury risk.

**Difference between sexes:** Women suffer disproportionately higher rates of exertional tibial pain in military and exercise related leg pain. Also, females demonstrate greater frontal and transverse plane motion than males during running. Specifically, females exhibit greater peak hip IR, hip adduction and greater peak knee valgus.

In this study, secondary analyses were performed between sexes within each group to establish if sex proved to be a distinguishing factor. Within the MSP group on the involved side (Table 2), PT was significantly greater in females as compared to males. Within the control group, there were no significantly different variables (in a randomly chosen limb) between sexes (Table 3). It is not clear how this variation may have affected the main findings of this study, but it appears that females may be at higher risk for MSP due to the tendency for greater pelvic and hip excursion during running. To further understand these differences, future studies should focus on one gender.

**Limitations**

It is worth noting that all runners were able to perform the treadmill running without difficulty or reported symptoms. It could be argued that treadmill running does not simulate over-ground running, but the authors felt that for this study, treadmill running would allow the runners to achieve their normal running speed versus running on the short runway in the experimental lab. Additionally, the authors chose to have the subjects run at their self-selected speed to minimize kinematic variation in them running at a speed that was unnatural to them. Further, subjects wore their own shoes and orthotics to help minimize variation from their normal kinematics. The authors believe that using standardized shoes is artificial for the subject and may change their running pattern.

This study only investigated a few select variables that may distinguish between those with a history of MSP and those without. The authors acknowledge that they may excluded other variables that are important determinants of injury, such as muscle strength and delayed onset of muscle activation. Additionally, the data collected was retrospective; therefore it is impossible to discern if the potential differences between groups occurred prior to or after the onset of MSP.

**CONCLUSIONS**

Despite its high prevalence, little is known regarding the kinematic factors associated with MSP. There is a need to understand the risk factors associated with MSP so that effective prevention strategies can be developed and implemented. Individuals with a history of MSP demonstrated significantly greater frontal plane PT, peak hip IR, and less knee flexion as compared to a matched group of runners without pain. Normal loading in the presence of abnormal movement can contribute to increased injury risk. Valuable insight can be gained by considering the entire lower extremity.

**REFERENCES**


ABSTRACT

Introduction/Purpose: Shoulder dysfunction and injury are common in throwing athletes. Loss of internal rotation has been correlated to shoulder pathologies. The purpose of this study was to assess the effects of a stretching protocol on passive internal rotation. The purpose of this study was assess the effects of a stretching protocol on passive internal rotation motion in the throwing shoulders of collegiate baseball players.

Study Design: Pre-Post, intervention, using a within subjects comparison of a convenience sample.

Methods: Glenohumeral internal rotation and external rotation of the throwing and non-throwing shoulders of NCAA Division I baseball players were measured using a universal goniometer. Determinations were made as to the degree of Glenohumeral Internal Rotation Deficit (GIRD) in the throwing shoulder. A daily (5 days per week), 12-week posterior capsule stretching program was administered. Post-stretching internal rotation and external rotation measures were again obtained. The coaches and athletic trainers of the included team monitored the players for shoulder injuries and innings of training/competition lost due to shoulder injuries during the 12 week intervention.

Results: A significant increase in range of motion was found for dominant arm internal rotation (IR) and total range of motion (TOT) following the stretching program. No statistically significant improvement in range of motion was found for external rotation (ER), non-throwing arm internal rotation (NDIR), non-throwing arm external rotation (NDER), and non-throwing arm total motion (NDTOT).

Conclusions: Implementation of a posterior capsule stretching program may be helpful to facilitate increased passive internal rotation range of motion at the glenohumeral joint. Further research should be performed using a control group not receiving the stretching program in order to more completely establish the impact of stretching on measures of passive glenohumeral range of motion.

Key Words: GIRD, glenohumeral internal rotation, stretching

Level of Evidence: 1b
INTRODUCTION
The throwing motion in the overhead-throwing athlete, such as a baseball player, is a complex biomechanical phenomenon. This highly skilled movement, performed at extreme velocities, requires a delicate combination of flexibility, strength, coordination, synchronicity, and neuromuscular control. The athletes’ throwing shoulder must exhibit adequate dynamic stability that provides sufficient mobility to accommodate the throwing motion, while preserving stability needed to prevent symptoms and/or injury.¹

In previous studies,²⁻⁵ altered mobility patterns have been reported in the throwing shoulder of baseball players, especially when compared to the non-throwing shoulder. The throwing shoulder typically presents with hypermobility in some directions while demonstrating hypomobility in others. This atypical mobility pattern may be attributed to the structural changes found in the glenohumeral joint capsule, labrum, rotator cuff musculature, ligaments, and osseous structures that occur in response to the demands of overhead throwing. The throwing motion used in baseball requires the arm to be forcefully propelled forward from a position of full external rotation to near full internal rotation. The posterior rotator cuff must act in an eccentric fashion to decelerate and control the arm as it internally rotates and horizontally adducts across the body.⁶

Previous authors have suggested that the throwing shoulder typically exhibits increased external rotation and decreased internal rotation when compared to the non-throwing shoulder. This loss of internal rotation in the throwing shoulder is defined as the glenohumeral internal rotation deficit (GIRD).⁷ Both soft tissue and osseous tissue changes have been linked to GIRD. Increased external rotation and decreased internal rotation in the dominant extremity have been correlated with an increase in humeral retroversion.⁸ From a soft tissue perspective, asymmetric capsular tightness (especially posterior tightness) has also been suggested as a cause of the observed loss of internal rotation.⁷ In a study by Burkhart, et al, evidence was presented to support the prediction that asymmetric glenohumeral capsular tightness could contribute to a wide variety of pathologies.⁹ As a result of Burkhart’s work, those who care for pitchers in professional baseball have begun to develop stretching programs to address internal rotation deficits. These programs have been reported to be effective at reducing innings lost and surgical procedures performed on the throwing shoulder of professional pitchers.¹⁰

Craig Morgan, MD explained the concept known as the pathological cascade of the throwing shoulder. He stated that the first sign of shoulder pathology is a painless loss of velocity and command caused by an early loss of glenohumeral internal rotation secondary to a posterior capsule contracture. Once this cascade has begun, the GIRD will cause the posterior inferior capsular contracture to become progressively less mobile. This increased posterior tightness, Morgan asserted, would lead to posterior shoulder stiffness and an inability to properly prepare for competition.¹¹ Progression of the cascade includes a third stage that presents as posterior shoulder pain without mechanical symptoms. This pain is felt during the late cocking and early acceleration phases of the throwing cycle due to posterior superior glenohumeral instability. The posterior inferior capsular contracture forces the humerus into a posteriorly and superiorly shifted position, adding undue strain on the posterior superior labral-glenoid complex. This posterior superior shifting allows an increase in external rotation that places the posterior superior rotator cuff in position to contact the glenoid margin resulting in symptoms of internal impingement. The contracture and resultant posterior superior shift lead to the development of mechanical symptoms usually evident in the late cocking and early acceleration of the players throwing phase, representing the fourth stage of the cascade. These symptoms occur due to the subsequent failure of the bicep and posterior superior labrum anchor, secondary to the capsular contracture.¹¹ This loss in anchoring tension on the glenoid attachments allows anterosuperior translation of the humeral head during forced humeral elevation and internal rotation, as seen with overhead throwing, leading to the “SLAP event” (Superior Labral Anterior-Posterior) and subsequent tearing of the posterior superior labral rim.¹² According to Morgan, the SLAP event can be avoided by initiating posterior capsular stretches early in the cascade to eliminate contracture. Once the SLAP event has occurred, mechanical symptoms most often become a surgical issue. As the player continues to throw through these symptoms, subacromial and rotator cuff symptoms will develop.¹¹
In some cases of GIRD there may be no increase in external rotation. In these cases there exists a likelihood of pathological internal impingement. Myers et al stated that throwers with pathologic internal impingement will exhibit significantly increased posterior shoulder tightness and glenohumeral internal rotation deficit without significantly increased external rotation gain. Based on the review of the related literature, the authors of the current study decided to assess the glenohumeral internal and external rotation range of motion of the shoulders of NCAA Division I baseball players.

Therefore, the two specific purposes of this research were: 1) to determine the prevalence of glenohumeral internal rotation deficit in the sample of Division I collegiate baseball players, and 2) to determine the effectiveness of a twelve-week posterior capsule stretching program on GIRD.

The authors hypothesized that the posterior capsule stretching program would statistically improve the internal rotation measures over a twelve week period.

**METHODS**

A sample of convenience obtained from a NCAA Division I baseball team (n = 28; all members of the team) was used to conduct this study. Descriptive characteristics for subjects are displayed in Table 1. The study design and data collection methods were approved by the University (can reinsert the identifier) Institutional Review Board (IRB) for Research with Human Subjects and all subjects provided informed consent prior to participating in the study. Range of motion was assessed prior to and following a daily (five days per week) 12-week posterior capsule stretching program. Measurements included internal rotation (IR), external rotation (ER), and total motion arc (TOT) of the throwing arm and internal rotation (NDIR), external rotation (NDER), and total motion arc (NDTOT) of the non-throwing arm using a plastic, universal goniometer with the scapula stabilized as described by Norkin and White. In order to obtain goniometric measurements, the subjects were positioned supine, the arm being measured was placed in 90 degrees shoulder abduction with the elbow at 90 degrees flexion. All motions were measured passively. All measurements were performed by graduate physical therapy students who had been trained by the authors. Passive force was applied by the examiner until non-glenohumeral accessory motion was observed. Prior to data collection a pilot study was performed to develop research protocols and train data collectors. Each of the data collectors demonstrated test – retest reliability before collecting data presented in this research. Initial measures were made at the beginning of the fall term as the players reported for fall practice. Post-intervention measures were made three months later at the end of the fall training/competition period.

While all players were involved in the daily posterior capsule stretching program, some players were found to initially have significant internal rotation deficits, that is to say, they exhibited GIRD. To place a subject in the GIRD category the authors chose to require that the subject’s internal rotation deficit must have exceeded the bounds of two out of three accepted definitions of GIRD.

If the difference between the internal rotation of the non-throwing shoulder versus throwing shoulder was greater than 20 degrees (GIRD), the difference between internal rotation of the throwing shoulder and the non-throwing shoulder was greater than 10% of the total rotation (internal rotation + external rotation) of the non-throwing shoulder (GIRD), and the difference between internal rotation of the throwing shoulder and the non-throwing shoulder was greater than 20% of the internal rotation of the non-throwing shoulder (GRID).

To the authors’ knowledge, the players did not previously participate in an internal rotation stretching program prior to this data collection. The baseball program training staff was instructed in the posterior capsule stretching program. Each day of practice or competition included the stretching exercises supervised by the training staff. Each stretch was performed 3–5 repetitions. Each repetition was held for 30 seconds. The stretching program lasted for a period of twelve weeks. The stretches used can be seen in Figures 1–6. They were collectively known as sleeper stretches.

<table>
<thead>
<tr>
<th>Table 1. Physical characteristics of participants.</th>
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</thead>
<tbody>
<tr>
<td>Variable</td>
</tr>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>Height (cm)</td>
</tr>
<tr>
<td>Mass (kg)</td>
</tr>
<tr>
<td>Values presented are mean ± SD.</td>
</tr>
</tbody>
</table>
Figure 1. Sleeper Stretch 1, performed in prone.

Figure 2. Sleeper Stretch 2, performed in prone with scapular stabilization.

Figure 3. Sleeper Stretch 3, traditional position, self-stretch performed in sidelying with arm at 90 degrees of abduction.

Figure 4. Sleeper Stretch 4, alternate sidelying position, self-stretch with arm elevated above 90 degrees.

Figure 5. Sleeper Stretch 5, alternate sidelying position, self-stretch with arm at 45 degrees.

Figure 6. Sleeper Stretch 6, passive stretch performed in supine, with stabilization of the scapula.
IR and TOT following the stretching program. There was no statistically significant improvement in range of motion found for ER, NDIR, NDER, and NDTOT. Prior to the stretching intervention 10 of the 28 or 36% subjects were considered to have GIRD by the standards established for this research. Following the stretching intervention only 6 players met the criteria set to be classified as exhibiting GIRD (21% of subjects). Collectively, this represents a 15% decrease in the number of athletes exhibiting GIRD following the 12-week stretching regimen. During the period of stretching intervention there were no reported innings or games lost due to shoulder pain or injury. Furthermore, no medical or rehabilitative (other than the stretching program) treatments to the throwing shoulder were required for any of the subjects who met the GIRD criteria.

DISCUSSION

The throwing shoulder of overhead athletes must be able to tolerate extreme forces of torque and velocity while accommodating significant range of motion. The throwing motion can place a dramatic stresses upon the soft tissues supporting the glenohumeral joint. The balance of range of motion and stability needed to protect the throwing shoulder from injury while providing for effective performance is difficult to achieve and maintain due to the repetitive stresses, soft tissue adaptations, and the potential presence of osseous anomalies (humeral retroversion) associated

At the end of the twelve weeks of stretching, measures of glenohumeral rotation were again collected. Range of motion was assessed in order to determine IR, ER, TOT, NDIR, NDER, NDTOT and the presence of GIRD prior to and following the stretching program. Analysis of variance was performed in order to determine differences within the cohort following the stretching program with the level for statistical significance set at $\alpha \leq 0.05$.

RESULTS

Results of analysis of variance are presented in Table 2. A significant increase in range of motion was found for

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pre-Stretching</th>
<th>Post-Stretching</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Throwing Arm</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Rotation (IR)</td>
<td>48.89 ± 8.46</td>
<td>54.07 ± 13.85</td>
<td>0.04*</td>
</tr>
<tr>
<td>External Rotation (ER)</td>
<td>105.07 ± 13.43</td>
<td>106.89 ± 10.91</td>
<td>0.29</td>
</tr>
<tr>
<td>Total Motion Arc (TOT)</td>
<td>153.96 ± 13.55</td>
<td>160.96 ± 16.98</td>
<td>0.04*</td>
</tr>
<tr>
<td><strong>Non-Throwing Arm</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Rotation (NDIR)</td>
<td>61.57 ± 10.69</td>
<td>63.10 ± 14.65</td>
<td>0.32</td>
</tr>
<tr>
<td>External Rotation (NDER)</td>
<td>94.00 ± 17.13</td>
<td>92.82 ± 13.24</td>
<td>0.38</td>
</tr>
<tr>
<td>Total Motion Arc (NDTOT)</td>
<td>155.57 ± 23.28</td>
<td>155.92 ± 20.99</td>
<td>0.47</td>
</tr>
</tbody>
</table>

Values presented are mean ± SD.
* Significantly different from pre-stretching ($p \leq 0.05$).

Figure 7. Comparison of Internal and External rotation, pre- and post-intervention. *Denotes statistically significant difference.
with overhead throwers. Once this “balance” is disrupted, continued throwing at a competitive intensity can lead to stresses that begin the pathological cascade.\textsuperscript{11} Whether the changes seen in the shoulders of overhead throwers are acquired or congenital, the throwing motion shifts the total arc of motion toward external rotation and diminishes internal rotation. Soft tissue adaptations that result can be addressed by consistent participation in a stretching program focused on internal rotation.\textsuperscript{7} While the protocol used in the current study did not include joint mobilization, recent evidence suggests that non-angular (joint mobilizations) stretching can be effective in addressing internal rotation deficits.\textsuperscript{17} Cools et al reported that joint mobilization could be as effective as angular stretching exercises to address GIRD.\textsuperscript{17} One might conclude, based on the study cited above and those already mentioned, that GIRD can be the result of adaptive changes in contractile tissue, non-contractile soft tissue, and bony anomalies that are likely congenital. It is possible that no matter the source of the internal rotation deficit, regular stretching may be beneficial to any athlete who throws overhead. Also important to consider is the fact that even those in the current study who did not exhibit GIRD did exhibit improvements in range of motion. If one accepts the idea of a progressive cascade leading to shoulder pathology, stretching those who perform the act of throwing overhead, whether GIRD is present or not, might be a effective preventative intervention.

The current study, like previous studies of professional overhead throwing athletes,\textsuperscript{7} supports the implementation of a daily stretching program. The results of the current study demonstrated that this stretching protocol has the ability to increase shoulder internal rotation and total motion arc in the throwing shoulder of collegiate baseball players. Such a program can facilitate increases in internal rotation passive range of motion, and may promote posterior glenohumeral capsular and posterior rotator cuff length which could reduce lost performance time due to shoulder injury. During this 12-week stretching program the athletes experienced no shoulder injuries. It is possible that the stretching program positively contributed to this absence of injury.

The ability to generalize these results is limited due to the lack of a control group. Because these athletes were all interested in optimal performance, no “at risk” throwers were left untreated to measure whether the incidence of shoulder problems would have been greater without the stretching protocol. The authors of the current study were interested to see that no increases in ROM were seen in the non-throwing, non-stretched upper extremity. In this sense the athletes served as their own controls. While generalization of results may be somewhat limited due to lack of a true control group, this dominant to non-dominant comparison supports the conclusions drawn by the authors.

Future studies should include a control group for comparison and/or a group receiving joint mobilization of the glenohumeral and scapulothoracic articulations. The authors plan to continue this line of research longitudinally over the course of these subjects' playing careers to assess the long term effects of a comprehensive stretching program.

**CONCLUSION**

Implementation of a posterior capsule stretching program may be helpful to facilitate an increase in passive internal rotation range of motion in the dominant (throwing) shoulder of collegiate baseball players. Such a stretching program may be useful as a means of reducing innings lost due to injury in collegiate baseball players. Further research should be performed using a control group not receiving the stretching program in order to more effectively evaluate the impact of a comprehensive stretching program as a means of preventing GIRD related shoulder pathology in overhead throwing athletes.

**REFERENCES**

4. Jobe CM, Pink MM, Jobe FW, Shaffer B. Anterior shoulder instability, impingement, and rotator cuff


ABSTRACT

Background: Swiss ball training is recommended as a low intensity modality to improve joint position, posture, balance, and neural feedback. However, proper training intensity is difficult to obtain during Swiss ball exercises whereas strengthening exercises on machines usually are performed to induce high level of muscle activation.

Purpose: To compare muscle activation as measured by electromyography (EMG) of global core and thigh muscles during abdominal crunches performed on Swiss ball with elastic resistance or on an isotonic training machine when normalized for training intensity.

Methods: 42 untrained individuals (18 men and 24 women) aged 28-67 years participated in the study. EMG activity was measured in 13 muscles during 3 repetitions with a 10 RM load during both abdominal crunches on training ball with elastic resistance and in the same movement utilizing a training machine (seated crunch, Technogym, Cesena, Italy). The order of performance of the exercises was randomized, and EMG amplitude was normalized to maximum voluntary isometric contraction (MVIC) EMG.

Results: When comparing between muscles, normalized EMG was highest in the rectus abdominis (P < 0.01) and the external obliques (P < 0.01). However, crunches on Swiss ball with elastic resistance showed higher activity of the rectus abdominis than crunches performed on the machine (104 ± 3.8 vs 84 ± 3.8% nEMG respectively, P < 0.0001). By contrast, crunches performed on Swiss ball induced lower activity of the rectus femoris than crunches in training machine (27 ± 3.7 vs 65 ± 3.8% nEMG respectively, P < 0.0001). Further, gender, age and musculoskeletal pain did not significantly influence the findings.

Conclusion: Crunches on a Swiss ball with added elastic resistance induces high rectus abdominis activity accompanied by low hip flexor activity which could be beneficial for individuals with low back pain. In opposition, the lower rectus abdominis activity and higher rectus femoris activity observed in machine warrant caution for individuals with lumbar pain. Importantly, both men and women, younger and elderly, and individuals with and without pain benefitted equally from the exercises.

Key Words: abdominal crunch, elastic resistance, electromyographic activity, exercise ball
INTRODUCTION

Core muscles must produce sufficient and well-coordinated muscle contraction to both support and stabilize the lumbar spine during a variety of human movement tasks.\textsuperscript{1,2} Stability in this inherently unstable area is obtained through the integration of the passive spinal column restraints, active spinal muscular control, and neurological control.\textsuperscript{3} Core stability refers to the ability of core muscles to stabilize the spine whereas core strength denotes the ability of the core musculature to then produce the needed contractile force and intra-abdominal pressure for movement.\textsuperscript{4} The theory of local and global muscles has been used to classify the muscles contributing to core stability.\textsuperscript{5} Local muscles, such as the transversus abdominis and multifidi, are primarily responsible for force generation that provides inter-segmental stability due to their attachment to the lumbar vertebra, whereas the global muscles, such as rectus abdominis and erector spinae, are primarily involved in spinal movement and control of external forces that are placed upon the spine.\textsuperscript{5,6}

The precise cooperation of motor control and contractile strength of the abdominal musculature provides support of the spine\textsuperscript{7} whereas inadequate abdominal muscle strength negatively influences both the stability and controlled mobility of the trunk and spine and have been associated with clinical implications such as low back pain.\textsuperscript{8} Jeng et al\textsuperscript{9} described that strengthening the back, legs and abdominal muscles may decrease the occurrence of LBP possibly through subsequent stabilization of the spine. Thus, health professionals advocate strengthening exercises for the abdominal muscles in order to increase stability of this inherently unstable area. Stability may be able to assist in reducing anteriorly directed shear forces on the lumbar spine through the preservation of balanced trunk muscle function and proper body posture.\textsuperscript{7}

One common abdominal exercise, the crunch, is frequently performed on an exercise machine. This exercise is designed to specifically isolate and strengthen the abdominal muscles with the possibility to adjust for intensity by increasing or decreasing load on the weight stack. According to Bergmarks\textsuperscript{5} description of local and global muscles, this exercise is focused on increasing the capacity of the global muscles. This is done by producing movement of the spine, which emphasizes the use of the global musculature. It should be noted that both the local and global systems theoretically work synergistically, which means, that isolation of the global system is improbable. The physical dimensions and the price of such abdominal training machines limit its use to gyms or hospital settings. Thus, easy to use alternatives to strengthen the global abdominal muscles are needed.

Abdominal exercises performed on a Swiss ball (exercise ball) have been widely used in both rehabilitation and clinical settings. The unstable surface of the Swiss ball may ease the stress around the hip and low back region and alter proprioceptive demands thereby enhance motor control of the local core muscles important for balance and stability.\textsuperscript{10-13} Further, the comfort provided by the cushioning of the ball may promote exercise compliance\textsuperscript{12} making it a simple and affordable alternative to traditional abdominal training machines present in the gym. In line with this, Behm at al\textsuperscript{14} suggested that Swiss ball exercises are useful for stability enhancement, balance assessment, inducing proprioceptive alterations, but not for increasing muscle strength. Swiss ball training is therefore only recommended as a low threshold modality to improve joint position, posture, balance, and neural feedback.\textsuperscript{15,16}

Training intensity is a paramount variable when designing resistance training programs. Numerous studies have used electromyography (EMG) to evaluate muscle recruitment during rehabilitation and strength training exercises based on observations of a positive and linear relationship between EMG amplitude and isometric force output.\textsuperscript{17-20} EMG activity of at least 60% of maximal voluntary isometric contraction (MVIC) is required to obtain the desired physiological adaptations in terms of efficient strength gain, neural adaptations, and muscle fiber hypertrophy.\textsuperscript{21,22} Rectus abdominis activity ranging from 30-60% has been reported in the literature for abdominal exercises on the Swiss ball.\textsuperscript{10,23} Thus, with proper regulation of intensity during crunches on a Swiss ball this exercise may function as more than a low threshold rehabilitation tool and be appropriate for inducing a training response capable of inducing strength gains. Elastic resistance may provide adequate additional loading that would make crunches on a Swiss ball an effective global muscle strengthening exercise.
The purpose of this study was to compare muscle activation of global core and thigh muscles during abdominal crunches performed on a Swiss ball with added elastic resistance and on an isotonic abdominal training machine. It was hypothesized that no statistically significant difference would exist in nEMG during the ab-crunch on the Swiss ball with elastic resistance and the sitting crunch performed on an isotonic abdominal training machine when normalised for training intensity.

METHODS

Participants
A group of 42 untrained adults (24 women and 18 men) were recruited from a large workplace with various job tasks. Exclusion criteria were blood pressure above 160/100, spinal disc herniation, rheumatoid arthritis, or other serious musculoskeletal disorders. The participants rated their musculoskeletal pain in the low back during the last 3 months on a 10 point Visual Analog Scale (VAS 0-10) where 0 is “no pain” and 10 is “worst pain imaginable”. Table 1 shows demographics and prevalence of musculoskeletal pain symptoms among subjects. All subjects performed testing using both elastic resistance on Swiss ball and the isotonic abdominal training machine.

Table 1. Demographics and pain intensity (worst pain in the low back) of the men and women of this study. Pain cases were defined as those having pain intensity of at least 4 in the low back and controls as those having a pain intensity of 3 or less. Mean (SD).

<table>
<thead>
<tr>
<th></th>
<th>Men</th>
<th></th>
<th>Women</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Pain</td>
<td>Control</td>
<td>Pain</td>
</tr>
<tr>
<td>N</td>
<td>11</td>
<td>7</td>
<td>19</td>
<td>5</td>
</tr>
<tr>
<td>Age, yrs</td>
<td>37 (12)</td>
<td>45 (15)</td>
<td>44 (9)</td>
<td>45 (9)</td>
</tr>
<tr>
<td>Height, cm</td>
<td>179 (7)</td>
<td>177 (7)</td>
<td>165 (7)</td>
<td>167 (3)</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>79 (9)</td>
<td>76 (7)</td>
<td>66 (12)</td>
<td>59 (5)</td>
</tr>
<tr>
<td>BMI</td>
<td>25 (2)</td>
<td>24 (2)</td>
<td>24 (5)</td>
<td>22 (2)</td>
</tr>
<tr>
<td>Pain intensity (0-10)</td>
<td>0.91 (1.2)</td>
<td>5.67 (1.9)</td>
<td>1.42 (1.3)</td>
<td>5.0 (1.2)</td>
</tr>
</tbody>
</table>

Maximal voluntary isometric contraction (MVIC)
Prior to the dynamic exercises described below, isometric MVIC ramp contractions (3 second duration) were performed according to standardized procedures during 1) static trunk flexion and extension (in standing posture and pelvis fixated while the trunk was flexed/extended against a rigid band) to induce a maximal EMG response in the tested muscles, 2) static hip adduction (laying flat on the back and pressing the knees against a solid ball), 3) static hip abduction (laying flat on the back and pressing the knees outwards against a rigid band) and 4) static hip extension (laying flat on the stomach with the knee flexed (90°) and pressing the foot upwards against the instructors hands), 5) static knee extension and flexion maneuvers (positioned in a Biodex dynamometer: knee angle: 70° and hip angle: 110°). Two isometric MVICs were performed for each muscle and the trial with the highest EMG was used for normalization of the peak EMGs recorded during the resistance exercises. Subjects were instructed to gradually increase muscle contraction force towards maximum over a period of two seconds, sustain the MVIC for three seconds, and then slowly release the force. Strong and standardized verbal encouragement was given during all trials.

Exercise equipment
Three different types of training equipment were utilized during the study: 1) elastic tubing (Thera-Band, The Hygenic Corporation, Akron, Ohio, USA),
2) inflatable Swiss ball (TheraBand, The Hygenic Corporation, Akron, Ohio, USA) 55 cm diameter was used for individuals with a height of 150-170 and 65 cm diameter was used for those with a height greater than 170 cm, and 3) an isotonic abdominal machine with loads ranging from 10 to 200 kg (Horizontal seated ab-crunch, Technogym, Cesena, Italy).

**Exercise description**

A week prior to testing, the participants performed a 10 repetition maximum test (10 RM) for all exercises. The individual 10 RM loading was found using one or a combination of several elastic tubes with resistances ranging from light to very heavy (red, green, blue, black, gray colors) to ensure that the 10 RM measurement was comparable with that obtained in the machine. On the day of EMG measurements participants warmed up with submaximal loads (2×10 repetitions with 50% of the 10 RM load) and then performed three consecutive repetitions with the 10 RM load after a 2-minute break. All exercises were performed in a slow and controlled manner, i.e. concentrically (~1½ sec) and eccentrically (~1½ sec) without sudden jerky movements or acceleration. The rest period between exercise conditions was approximately five minutes. The order of exercises was randomized for each subject by drawing a piece of paper from an opaque bag. Randomization was not stratified by pain level. The exercises are described below and shown in Figure 1.

**Ab-crunch on Swiss ball with elastic resistance (Fig. 1a and 1b):** The participant was asked to lie on the Swiss ball and then walk the feet away while simultaneously going down into a lying position, allowing the ball to stop at the lumbar spine area of the lower back. The feet were placed approximately 2 feet apart while the knees were bent at a 90 degree angle for increased base of support and adequate

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**Figure 1.** Abdominal crunch using Swiss ball and elastic resistance, A = start position, B = end position. Abdominal crunch using isotonic abdominal machine, C = start position, D = end position. (Horizontal seated ab-crunch, Technogym, Cesena, Italy).
stability and balance. The hands were placed at shoulder level grasping the elastic resistance handles – the elastic tubing was stretched to double resting length at this point (Fig. 1). The participant was asked to curl the head, neck and shoulders up and towards the pelvis region. Following this concentric phase, the participant slowly returned to the starting position (eccentric phase).

**Ab-crunch in machine (Fig. 1c and 1d):** The participant was seated in the isotonic abdominal machine with the feet behind the ankle rollers and the hands holding the handles at shoulder level. The participant then curled the upper-body forward and downwards as guided by the rotation of the machine until maximal flexion was reached. The participant then initiated the eccentric phase by allowing the weight to pull the upper body into starting position.

**EMG signal sampling and analysis**

EMG signals were recorded from 13 muscles of the trunk: rectus abdominis, left and right external obliques, left and right erector spinae, and unilaterally on the dominant side (kicking leg) of gluteus maximus, gluteus medius, rectus femoris, vastus medialis and lateralis, adductor magnus, biceps femoris and semitendinosus. A bipolar surface EMG configuration (Blue Sensor N-00-S, Ambu A/S, Ballerup, Denmark) and an inter-electrode distance of 2 cm was used. Before affixing the electrodes, the skin of the respective area was prepared with scrubbing gel (Acqua gel, Meditec, Parma, Italy) to effectively lower the impedance to less than 10 kΩ.26 Electrode placement followed the SENIAM recommendations.25

The EMG electrodes were connected directly to wireless probes that pre-amplified the signal (gain 400) and transmitted data in real-time to a nearby 16-channel PC-interface receiver (TeleMyo DTS Telemetry, Noraxon, Arizona, USA). The dimension of the wireless probes was 3.4 cm × 2.4 cm × 3.5 cm. The sampling rate was set to 1500 Hz with a bandwidth of 10-500 Hz to avoid aliasing. The resolution of the signals was 16 bits. The common mode rejection ratio was better than 100 dB.

During later analysis all raw EMG signals obtained during MVICs as well as during the exercises were digitally filtered using 1) high-pass filtering at 10 Hz, and 2) a moving root-mean-square (RMS) filter of 500 ms. For each individual muscle, peak RMS EMG of the 3 repetitions performed was determined, and the average value of these 3 repetitions was then normalized to the maximal RMS EMG obtained during MVIC.26 Each muscle contractions start- (START) and end-time (END) point was located by the following routine; 1) locate the EMG peaks (MAX) separated by 1000 ms, 2) locate the minimum EMG (MIN) before and between each MAX. START is now located as the first index (searching from MIN) >5%*(MAXi-MIN)+ MIN, and END as the first index (searching from MAX) <5%*(MAXi-MIN)+ MIN. Based on this, contraction time (i.e. time under tension) was calculated for both exercises during all repetitions.

**Covariates**

Subjects included both males and females, younger and elderly, and individuals with and without musculoskeletal pain. Age was dichotomized to below and above 50 years of age. Musculoskeletal pain intensity was assessed on a 0-10 visual analog scale for the low back, where 0 is ‘no pain’ and 10 is ‘worst imaginable pain’. The authors subsequently dichotomized the musculoskeletal pain question by defining ‘pain’ as a score of 4-10 in the low back and ‘no or minor pain’ as 0-3. This cut-point was based on a previous study showing more clinically relevant findings at pain intensities of 4 or above.27

**Statistics**

A two-way (2 × 13) repeated analysis of variance (Proc Mixed, SAS version 9, SAS Institute, Cary, NC) was used to investigate whether differences existed between exercise conditions and muscles. Factors included in the model were Exercise (Swiss ball with elastic resistance and machine) and Muscle (the 13 muscles), as well as Exercise by Muscle interaction. We used gender, age and musculoskeletal pain as dichotomous multi-adjusted covariates in this analysis. Normalized EMG was the dependent variable. When a significant main effect was found relevant post hoc comparisons were utilized to locate what type of differences existed. Values are reported as least square means (SE) unless otherwise stated. P-values < 0.05 were determined to be significant.

A priori power analysis showed that 16 participants in this paired design were sufficient to obtain a statistical power of 80% at a minimal relevant difference of 10% and a type I error probability of 1%, assuming a
standard deviation of 10% based on previous research in the authors laboratory. 

RESULTS

Exercise evaluation
There was a significant muscle by exercise interaction (P<0.0001), i.e. muscle activity of the 13 investigated muscles varied differently across exercises.

When comparing across muscles, nEMG was generally highest in the rectus abdominis and oblique muscles (range 62-110% nEMG, Table 2). However, crunches with elastic resistance showed higher activity of the rectus abdominis than crunches performed on the isotonic machine (range 96-110 vs 76-91% nEMG respectively, P<0.0001, Table 2). By contrast, crunches in machine showed higher activity of the rectus femoris (range 57-72 vs 20-34% nEMG, P<0.0001, Table 2) than crunches with elastic resistance. Further, there was no main effect on contraction time (exercise duration) between the 2 exercises (3155±153 ms on Swiss ball vs. 3205±154 ms in machine, P=0.74).

Influence of gender, age and musculoskeletal pain
There were no significant main effects of gender, age and musculoskeletal pain on nEMG during the exercises. For women and men, respectively, nEMG averaged for all muscles was 33% (+/-1.8%) and 33% (+/-2.5%) % (P=0.78). For younger and elderly individuals, respectively, nEMG averaged for all muscles was 32% (+/-1.6%) and 34% (+/-2.9%) (P=0.21). For individuals without and with musculoskeletal pain, respectively, nEMG averaged for all muscles was 34% (+/-2.2%) and 32% (+/-2.1%) (P=0.18).

DISCUSSION

The main finding of the present study was that crunches performed on Swiss ball with added elastic resistance elicited higher normalized rectus abdominal activity than crunches performed on an isotonic training machine when normalized for training intensity. In contrast, the flexed hip position during the seated crunch in machine resulted in higher rectus femoris activation as compared to the Swiss ball crunch.

The current data indicate that sitting crunches in an exercise machine designed to isolate the abdominal muscles does not target this muscle group to the same extent as the supine crunch on the Swiss ball although both exercises caused high activation. Biomechanically, the seated position in the machine with near 90 degree flexion of both knee and hip promotes assisted hip flexor activity from the rectus femoris while bending the torso forward. The rectus femoris muscle functions over two joints as both a knee extensor and a hip flexor, however the authors

| Table 2. Between-exercise difference in nEMG (% of MVIC) of 13 selected muscles. Values are presented as mean ± SE and significant between-exercise differences are marked with * |
|----------------|----------------|
| Crunch (elastic) | Crunch (machine) |
| **Rectus Abdominis** | 104 (3.8) * | 84 (3.8) |
| External Obl. (left) | 86 (3.7) | 79 (3.8) |
| External Obl. (right) | 79 (3.8) | 71 (3.8) |
| Erector spin. (left) | 12 (4.8) | 20 (4.8) |
| Erector spin. (right) | 11 (4.5) | 14 (4.7) |
| *Gluteus Med* | 19 (3.7) | 15 (3.8) |
| *Gluteus Max* | 10 (3.8) | 5 (3.8) |
| Rectus Femoris | 27 (3.7) | 65 (3.8) * |
| Vastus Medialis | 22 (3.7) | 25 (3.8) |
| Vastus Lateralis | 16 (3.7) | 23 (3.8) |
| Biceps Femoris | 10 (3.7) | 5 (3.8) |
| Semitendinosus | 11 (3.7) | 4 (3.8) |
| **Adductor** | 19 (3.8) | 14 (3.8) |
hypothesize that the static flexed position of the knee makes it a dominant hip flexor. Further, the hold and fixation of the feet by the ankle bar can contribute to additional rectus femoris activity.28 Previous authors have reported that increased external load in the abdominal crunch exercise does not enhance rectus abdominis activity but instead increases the activation of the hip flexors,29,30 However, in the current study this was only the case for seated crunch in machine whereas the elastic assisted crunch on Swiss ball resulted in very high rectus abdominis nEMG with a concomitant low rectus femoris activity. The authors observed activation levels of more than 100% of nEMG for rectus abdominis during the Swiss ball crunch whereas values ranging from 30-60% of nEMG have been reported in the literature for abdominal exercises on the Swiss ball.10,23 Thus, it seems that the added external load provided by the elastic resistance can maximize abdominal activity and limit hip flexor activation simultaneously. Importantly, the muscle recruitment during these two exercises was equally high regardless of gender, age and pain intensity.

High activity from the hip flexors, such as rectus femoris or iliopsoas, can be unsuitable for persons with low back pain or lumbar instability in general. Increased hip flexor activity will cause an anterior tilt, increased lumbar lordosis, which potentially creating anteriorly directed shear forces on the lumbar spine. This combination may contribute to the genesis of low back pain.21,30,31 Therefore, abdominal crunches performed in an exercise machine, in a seated position may not be desirable for individuals with lumbar disk pathologies, low back pain, or weak abdominal musculature due to high rectus femoris activity. Instead, crunches with elastic resistance on Swiss ball could serve as isolated daily routine abdominal exercise for both prophylactic and rehabilitation purposes where limited hip flexor moment is desired.

In contrast to the seated crunch, crunch on a Swiss ball provides a neutral starting hip position, which seems to minimize hip flexor activity during the exercise. During a traditional crunch the resistance is provided solely by the body mass and the lever arm is constantly decreasing from start to end of the concentric (lifting) phase. However, by adding elastic resistance the loading is more uniform during the entire range of motion due to the elongation of the elastic material and the concomitant decrease in body mass lever arm as the concentric phase advances. Thus, at starting supine position with the greatest lever arm the traction from the elastic tubing is small compared with the resistance produced at higher elongation levels during the end of the concentric phase. Besides these biomechanical differences, the labile surface of the Swiss ball might also have contributed to the contrasting activation strategies of the rectus abdominis and rectus femoris muscles. It has been speculated, that the unstable surface provided by the ball alters proprioceptive demands thereby stimulating the core muscles to a greater extent than stable services, which may be important for balance and stability.10,13 However, in the present study no differences in oblique or erector spinae activation were observed, indicating that these muscles were not affected by exercise type. It is beyond the scope of the current study to determine the role of the local core muscles during these two exercise tasks as this would require intra-muscular EMG.

To obtain proper strength adaptations exercises that produce EMG activity of at least 60% of isometric MVC are recommended.21,22 Thus, both exercises were able to induce sufficient EMG activity to provide a stimulus for strengthening of the rectus abdominis and the obliques and should therefore also be considered as a high threshold rehabilitation tool by health professionals. The suggestion by Behm,14 that Swiss balls are useful for providing an exercise condition capable of increasing stability, balance and proprioception but not muscle strength may need to be re-evaluated in light of the current findings regarding the abdominal crunch performed on a Swiss ball with added elastic resistance. Future studies should address the more long term strength adaptations that may occur, along with changes in stability and proprioception in order to determine this.

Low back pain is traditionally associated with repetitive load handling and heavy manual labor. However, office work with a high degree of chair confinement (prolonged sitting) is also a frequently reported risk factor.32 Self-reported low back pain in subjects in the current study did not affect the muscle activation during the two exercises in office workers. However,
caution should be applied to this interpretation, as sensitization could have depressed muscle activation during the MVICs and thereby influenced the normalization of EMG. As strong abdominal muscles provide support for the lumbar spine during everyday movements strengthening the abdominal muscles may decrease the occurrence of low back pain.\(^7\)\(^8\) However, controversy exists with this assertion, and some authors have suggested that if the global muscles are over trained before the local muscles are sufficiently developed, it could result in situations where the force produced by the global muscles can not be controlled by the local musculature.\(^4\) Hence, abdominal training on the Swiss ball with added elastic resistance should be introduced thoughtfully, with gradual intensity progression in order to ensure optimal local musculature development before focusing on strengthening the global muscles.

Evaluations of abdominal exercises using nEMG comparisons has been based on identical movement velocity or cadence normalization using a metronome\(^13\),\(^23\),\(^33\),\(^34\) rather than loading intensity. In the present study identical contraction time and intensity (3 reps of 10 RM load) were used as normalization mediators to secure valid results. Further, the participants were accustomed to the exercises and performed a 10 RM test to determine appropriate intensity a week prior to testing. This study compared relative level of muscle activity across the two exercises. Thus, the effects of crunch on Swiss ball with added elastic resistance on muscle strength cannot be directly measured and a randomized controlled trial would be necessary to draw such conclusions. Further, the study population included working aged adults only, which limits the reported lack of an age effect to this relative narrow age-range.

CONCLUSION

Both crunches performed on a Swiss ball and on an isotonic training machine caused high activation of the abdominal muscles. Specifically, crunches on a Swiss ball with added elastic resistance induces high abdominal activity accompanied by low hip flexor activity, which could be beneficial for individuals with low back pain. Conversely, the lower levels of abdominal activity and higher levels of rectus femoris activity observed in the isotonic machine exercise warrant caution for individuals with lumbar pain. Importantly, both men and women, younger and elderly, and individuals with and without pain benefitted equally from the exercises.

REFERENCES


25. The SENIAM project (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles); available www.seniam.org. 2011. Ref Type: Internet Communication


ABSTRACT

Purpose/Background: A reduction in the maximal force output of muscles following pre-performance stretching has been reported. Several studies have suggested that localized vibration may enhance or replace stretching for gaining flexibility. It is important to know if localized vibration may also compromise muscle output. The purpose of this investigation was to determine the immediate effects of localized hamstring vibration on hamstrings (HAM) and quadriceps (QUAD) performance.

Methods: Thirty asymptomatic participants, 19 female and 11 male, mean age 25.4 years (±SD 2.7) received either five minutes of localized vibration to the right hamstrings at 30 Hz and 6 mm amplitude, or sham. One week later, each participant received the alternate treatment. Following treatments, right (R) and left (L) isometric HAM and QUAD strength was measured twice by handheld dynamometer and maximal horizontal hop distance of each lower extremity was measured by single leg hop test (SLH). Treatment outcomes were compared using paired t-tests. Treatment order effect was measured by independent T-test. Pre-study intrarater reliability for dynamometry was established using ICC(3,2).

Results: Mean (±SD) values for strength following vibration were 58.7 kg (15.7), 60.4 kg (14.0), 45.5 kg (14.2), 45.8 kg (13.2) for R QUAD, L QUAD, R HAM, L HAM respectively. SLH mean values were R SLH 153.8 cm (35 cm) and L SLH 155.4 cm (36 cm). There were no significant differences in means between vibration and sham treatment for any outcomes on either leg (p-values ranged .412-.971); p<.001 for all comparisons. Order had no significant effect (p-values .370-1.0). Intrarater ICCs were .888, .762, .884, .960 for R HAM, L HAM, R QUAD, L QUAD.

Conclusions: Unilateral application of localized vibration to the hamstrings at a duration previously reported to increase flexibility did not diminish the isometric performance of the hamstrings or quadriceps of either leg.

Level of Evidence: 1b

Key Words: hamstring, muscle performance, vibration
INTRODUCTION
There are many athletic and performing arts settings in which participants are likely to benefit from having an increase in muscle extensibility while maintaining the ability to achieve maximal muscular force output. A reduction in either of these attributes may result in compromised performance. While stretching techniques have proven effective at increasing muscle extensibility, previous studies have reported that both static and dynamic stretching may cause a reduction in maximal force output that may last up to two days. Two theories exist as to why stretching causes a decrease in force production: a) there is an alteration in the resting length of the individual contractile fibers that results in detrimental conditions in the length-tension relationship, and b) there is a decrease in neuromuscular activation as a result of central nervous system inhibition. While the exact mechanism by which stretching adversely affects muscle strength is not fully understood, it may be that vibration has neurophysiological ramifications similar to stretching, including alteration of the viscoelastic properties of the musculotendinous unit.

Sands et al, Kinser et al, and Issurin et al have shown that localized vibration enhances stretching as a way to increase muscle extensibility. Research using localized vibration at 30 Hz as part of a stretching warm-up demonstrated that gymnasts experienced a significant increase in range of motion in the hip joints. Durban et al found that localized vibration alone was equally effective as static stretching for enhancing hamstring passive mobility.

While there is considerable evidence in the literature that whole body vibration enhances muscle performance, fewer studies have examined the effects of localized vibration on muscle performance. Localized vibration is a technique in which an external vibratory stimulus is applied to a specific muscle, muscle group, or joint. The results of the localized vibration research are contradictory. A decrease in peak torque of the ankle plantar flexors has been reported following both passive stretching and localized vibration to the Achilles tendon. Similarly, in a more recent study by Herda et al, a decrease in voluntary peak torque of the ankle plantar flexors was found following both prolonged passive stretching and localized vibration. Conversely, Issurin et al reported that localized vibration applied for short periods of time produced increased gains in maximal strength and flexibility of the hamstrings. The limited evidence and conflicting results of these studies indicate the need for further research to determine if localized vibration has an effect on peak muscle strength. Vibration studies to date have used various vibration parameters. Vibration frequencies between 20 Hz and 50 Hz have produced inhibitory effects upon the targeted muscle, while frequencies above 80 Hz have produced excitation. In studies attempting to evaluate vibration as a modality to increase muscle extensibility, the frequency has varied from 30 Hz to 44 Hz and the amplitude has varied from 2 mm to 3 mm.

As far as tools for outcome measures, many options exist to measure hamstrings and quadriceps performance. Isokinetic dynamometry is considered to be the gold standard in assessment of peak muscle torque, but drawbacks of this method include the costly equipment requirements, the excessive amount of time required for setting up and running the dynamometer, and limited accessibility. Handheld dynamometry (HHD) and single-leg hop testing (SLH) are alternative lower extremity strength measurements that have been shown to be both reliable and valid, and are easy to administer and clinically available.

In summary, discovering if localized vibration is a viable means to attain similar gains in muscle extensibility as static stretching while avoiding any deficits in peak muscle strength would be important for the performance of many athletes. Previous research has reported localized vibration to be an effective way of increasing muscle extensibility, but the evidence remains divided as to whether vibration results in a decrease in muscular force output. If localized vibration can increase muscle extensibility without causing deficits in muscular force output, it may replace static stretching as a means of increasing flexibility before athletic competition or performances. Therefore, the purpose of this study was to determine the immediate effects of localized 30 Hz vibration, applied to the right hamstrings, on quadriceps and hamstrings performance as measured via peak isometric muscle strength.

It is hypothesized that applying localized vibration to the right hamstrings will have no effect on peak muscle strength. This determination would contribute to one
aspect of the ongoing discussion of localized vibration as an alternative to static stretching.

METHODS

A repeated measures cross-over design was used with independent variables of vibration treatment or sham treatment. The dependent variables were bilateral maximal isometric hamstrings and quadriceps contractions measured by HHD, and SLH for maximal horizontal distance of each lower extremity. A flow chart of participants is depicted in Figure 1.

Thirty asymptomatic university students (19 female, 11 male) between the ages 22-32 years (average age 25.4 years, SD 2.7) were recruited by word of mouth to participate in this study. Inclusion criterion was that subjects had to be able to move their knee against resistance through a full, normal range without pain. Participants were excluded if they reported any of the following: taking prescription blood thinners, known pregnancy, history of hamstrings or quadriceps injury within the last year, disc problems, sciatica, osteoporosis, knee instability, or bleeding disorders. None of the potential participants had to be excluded. Before participating, subjects were informed of possible risks and signed an informed consent form approved by the University of Puget Sound Institutional Review Board.

Prior to the onset of this study, 30 university students volunteered to participate in a pilot study to establish the intrarater reliability of the researcher performing the HHD measurements. Subjects of the pilot study were tested in the same position, and with the same timing, as the subjects in the study.

At initial visit, participants were randomly assigned to one of two treatments: 1) localized vibration, 2) sham technique. Random assignment was initiated by having the first participant draw a piece of paper from a hat. The paper had either “A” or “B” written on it, with “A” correlating to the localized vibration, and “B” correlating to the sham technique. After the first subject drew, the treatments were alternated for the remaining participants. Participants then received the assigned intervention and the outcome measures of right and left hamstrings and quadriceps peak strength, and SLH were assessed. At the second visit, one week later, subjects received the alternate treatment and outcome measures were tested again.

The vibration treatment consisted of five minutes of localized vibration applied directly to the right hamstrings using the Thumper Versa Pro Massager (Thumper Massager Inc. Markham, Ontario) set to 30 Hz with 6 mm of amplitude. Subjects were in a seated position with the hips flexed at 90° for the duration of the treatment (Figure 2). The sham treat-
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The sham treatment consisted of a mock neurological approach. For five minutes, subjects solved brain puzzles purchased at a grocery store newsstand that required processing of visual stimuli. Since this task predominantly involved the right cerebral hemisphere and the right hamstrings were being tested, direct neurologic influence on motor tasks would be minimized. Again, subjects were seated with the hips flexed at 90° for the duration of the sham treatment (Figure 3).

Immediately following each intervention, subjects proceeded to isometric testing of quadriceps and hamstrings peak strength, and then to a SLH for distance. Peak quadriceps strength was tested first followed by peak hamstrings strength for each subject. Testers of all outcome measures were blinded to which treatment subjects had received. To determine maximal isometric muscle strength, the tester secured a handheld MicroFET 2 dynamometer (Hoggan Health Industries, 8020 South 1300 West, West Jordan, UT 84088) against the distal, anterior tibia for quadriceps testing and against the Achilles tendon for hamstrings testing. For quadriceps testing, subjects were seated at the edge of a treatment plinth positioned so that both feet were off the ground, hips and knees both flexed at 90°. Subjects were instructed to fold their arms across their chest and maximally extend their knee against the tester’s resistance. Subjects attempted two sub-maximal trials in each position for familiarization, followed by two recorded maximal contractions. The duration of each maximal effort was five seconds, with a 30-second rest in between trials, and a one-minute rest before testing the other side.

Subjects then performed SLH for maximal horizontal distance with measurement being taken from initial heel position to heel contact at landing. Each subject was allowed two practice jumps before the recorded jump. Subjects were instructed to “stick the landing” so that the foot did not move after initial contact and the untested foot did not touch the ground. After a one-minute rest, the opposite leg was tested. The mean of 2 dynamometry trials for each muscle group on each leg and the SLH distances of each leg were used in analysis.

**STATISTICAL ANALYSIS**

A two-way mixed intra-class correlation coefficient with average measures (ICC(3, 2)) was performed on pilot data to establish intrarater handheld dynamometer reliability. The data collected were normally distributed. A paired t-test was used to compare mean hamstrings and quadriceps forces and single-leg hop scores between vibration and sham applications. An independent T-test was used to compare means by treatment order. The alpha level for statistical significance was set, a priori, at 0.05. All data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 19.

**RESULTS**

ICC(3,2) scores obtained from the pilot study demonstrated high intra-rater reliability. The scores for each measurement were .888, .762, .884, .960 for R HAM, L HAM, R QUAD, L QUAD respectively.

The mean and standard deviation values for maximal isometric quadriceps and hamstrings strength in kilograms for the right and left legs, following localized vibration and the sham treatment are listed in Table 1. Table 2 lists mean and standard deviation values for SLH for maximal horizontal distance in centimeters for the right and left legs following localized vibration and the sham treatment.

Paired t-tests demonstrated no statistically significant differences in means between vibration and
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sham treatment for any outcomes on either leg. The p-values for each comparison were .412, .666, .971, .730, .480, and .840 for R SLH, L SLH, R Quad, L Quad, R Ham, and L Ham respectively. Figures 4 and 5 illustrate the mean scores for maximal isometric contraction and SLH respectively under both conditions. Table 3 lists the results of the independent T-test, indicating that treatment order had no significant effect on mean scores for any measurement on either leg (p-values .152-1.0).

**DISCUSSION**

The results of this study suggest that the application of localized vibration to the right hamstrings will not result in a change in muscle performance of the hamstrings or quadriceps of either leg as noted during an isometric assessment and functional testing. The five-minute length of localized vibration treatment was selected as this length of exposure was equally as effective as static stretching for enhancing hamstring passive mobility when utilized by Durban et al. Subjects of this study were tested for bilateral hamstrings and quadriceps strength and performance although localized vibration was only applied

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**Table 1.** Mean ± standard deviation values for hamstring and quadricep strength bilaterally, following localized vibration and sham treatment, measured by handheld dynamometry in kg.

<table>
<thead>
<tr>
<th></th>
<th>R Quad after vibration</th>
<th>L Quad after vibration</th>
<th>R Ham after vibration</th>
<th>L Ham after vibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>58.76 (±15.7)</td>
<td>60.47 (±14.0)</td>
<td>45.55 (±14.2)</td>
<td>45.81 (±13.2)</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>58.8 (±16.1)</td>
<td>60.01 (±16.6)</td>
<td>46.11 (±15.4)</td>
<td>45.61 (±14.5)</td>
</tr>
</tbody>
</table>

**Table 2.** Mean ± standard deviation values for single leg hop test for maximal horizontal distance bilaterally, following localized vibration and sham treatment, measured in cm.

<table>
<thead>
<tr>
<th></th>
<th>R SLH after vibration</th>
<th>L SLH after vibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>153.83 (±35.0)</td>
<td>155.40 (±36.3)</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>155.78 (±35.2)</td>
<td>156.36 (±35.7)</td>
</tr>
</tbody>
</table>

**Table 3.** Independent T-test p-values showing that treatment order had no significant effect on mean scores for any measurement on either leg.

<table>
<thead>
<tr>
<th></th>
<th>R SLH after vibration</th>
<th>L SLH after vibration</th>
<th>R Quad after vibration</th>
<th>L Quad after vibration</th>
<th>R Ham after vibration</th>
<th>L Ham after vibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>p-value</td>
<td>.780</td>
<td>.370</td>
<td>.988</td>
<td>.681</td>
<td>.927</td>
<td>.841</td>
</tr>
<tr>
<td></td>
<td>R SLH after sham</td>
<td>L SLH after sham</td>
<td>R Quad after sham</td>
<td>L Quad after sham</td>
<td>R Ham after sham</td>
<td>L Ham after sham</td>
</tr>
<tr>
<td>p-value</td>
<td>.799</td>
<td>.831</td>
<td>.539</td>
<td>.152</td>
<td>.852</td>
<td>1.00</td>
</tr>
</tbody>
</table>
to the right hamstrings. Previous research has shown that unilateral application of localized vibration resulted in passive range of motion gains bilaterally.\(^{11}\) Testing of bilateral strength and performance was conducted to ensure that there were no deficits that carried over in the same manner as the passive range of motion gains. No changes in muscular strength occurred related to application of vibration, as measured isometrically or via a functional test.

Previous research has been conducted to investigate test-retest reliability, minimal clinically important difference, of isometric knee flexion and extension.\(^{18}\) It was determined that the smallest real difference was 28.2% and 21.5% for isometric knee flexion and extension respectively. The paired T-tests used to compare the mean values for isometric knee flexion and extension in the present study yielded p-values ranging from .412-.971. Thus, there was not a change in the peak isometric force the flexion and extension contractions great enough to indicate a genuine clinical change.

The findings of this study are useful in conjunction with previous research that has found that 5 minutes of localized vibration alone was equally as effective as static stretching for enhancing hamstring passive mobility.\(^{11}\) Both static and dynamic stretching have been shown to cause a decrease in maximal force output, and this reduction can last up to two days.\(^{2-4}\) Therefore, applying localized vibration to the hamstrings prior to athletic competition may be a viable alternative to stretching as a means to increase muscle extensibility without risking strength deficits. Physical therapists are often in a position to advise and educate patients on safety and methods of maximizing performance for athletic competition or general exercise. The findings of this study will allow physical therapists to provide patients with accurate information on the concurrent effect of localized vibration on isometric strength and muscle performance during the single limb hop.

A muscular strength imbalance between the hamstrings and quadriceps is an intrinsic risk factor for hamstring strains.\(^{26-28}\) Many athletes perform pre-activity stretching with the belief that increasing the flexibility of the hamstrings will reduce their risk of incurring a hamstring strain. However, they may, in fact, be placing themselves at an increased risk, as stretching may reduce hamstrings strength, thus increasing the muscular imbalance between the hamstrings and quadriceps.\(^{24}\) The results of the current study suggest that, if used for increasing muscle extensibility, localized vibration will not place athletes at an increased risk of hamstring strains due to any deleterious effect on hamstring strength.

There were several limitations present in this study. Researchers used handheld dynamometry and single-leg hop tests as strength measurements instead of the gold standard of isokinetic dynamometry. Although handheld dynamometry and single-leg hop tests have been shown to be both valid and reliable, they do not test the maximal force output throughout the entire range of motion as isokinetic dynamometry does.\(^{18-25}\) Handheld dynamometry only measures maximal force output at one standardized joint angle, and a single leg hop test has other factors involved, including balance, technique, and the many other segments in the kinetic chain. This study used a sample size of 30 participants. Future research with a larger sample size and with the use of isokinetic dynamometry to measure muscle strength would add credibility and strength to the results found in this study. Although the vibration frequency used in this study was the same as previous studies that have shown localized vibration to improve hamstrings extensibility,\(^{11}\) muscle extensibility was not measured in this study. Perhaps the disagreement between the current study and those reporting a loss of strength following localized vibration may be related to amplitude. An amplitude of 6 mm was used in the current study, in contrast to 2-3 mm amplitude that was used in other studies. The optimum amplitude, intensity, and duration parameters for localized vibration to achieve successful outcomes for length and strength have yet to be determined.

**CONCLUSION**

Localized vibration applied to the hamstrings of one lower extremity did not impair isometric or functional muscle output of the quadriceps or hamstrings bilaterally. When combined with findings from previous studies involving vibration and muscle extensibility, the current findings support the use of localized vibration as an alternative to static stretch. Further research is needed with larger sample sizes, isokinetic dynamometry, and development of vibration parameters for a protocol to be utilized with athletes.
REFERENCES

ABSTRACT

Background: The physical demands required of the body to execute a shot in golf are enormous. Current evidence suggests that warm-up involving static stretching is detrimental to immediate performance in golf as opposed to active dynamic stretching. However, the effect of resistance exercises during warm-up before golf on immediate performance is unknown. Therefore, the purpose of this study was to assess the effects of three different warm-up programs on immediate golf performance.

Methods: Fifteen elite male golfers completed three different warm-up programs over three sessions on non-consecutive days. After each warm-up program each participant hit ten maximal drives with the ball flight and swing analyzed with Flightscope® to record maximum club head speed (MCHS), maximal driving distance (MDD), driving accuracy (DA), smash factor (SF) and consistent ball strike (CBS).

Results: Repeated measures ANOVA tests showed statistically significant difference within 3 of the 5 factors of performance (MDD, CBS and SF). Subsequently, a paired t-test then showed statistically significant (p<0.05) improvements occurred in each of these three factors in the group performing a combined active dynamic and functional resistance (FR) warm-up as opposed to either the active dynamic (AD) warm-up or the combined AD with weights warm-up (WT). There were no statistically significant differences observed between the AD warm-up and the WT warm-up for any of the five performance factors and no statistical significant difference between any of the warm-ups for maximum clubhead speed (MCHS) and driving accuracy (DA).

Conclusion: Performing a combined AD and FR warm up with Theraband® leads to significant increase in immediate performance of certain factors of the golf drive compared to performing an AD warm-up by itself or a combined AD with WT warm-up. No significant difference was observed between the three warm-up groups when looking at immediate effect on driving accuracy or maximum club head speed. The addition of functional resistance activities to active dynamic stretching has immediate benefits to elite male golfers in relation to some factors of their performance.

Key Words: Active dynamic, functional resistance, immediate performance, golf, warm-up

Level of Evidence: This study is a Quantitative Experimental design using repeated measures and multiple cross-overs. It cannot be classified using the descriptive level of evidence.

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**INTRODUCTION**

Golf is an extremely popular sport played across the world regardless of gender, skill level or age. The physical demands required of the body to execute one of the most complex athletic skills are enormous. The golf swing is a highly coordinated, multi-segmental, rotational, closed chain activity, requiring strength, explosive power, flexibility and balance. Elite golfers have been shown to possess more of these unique physical characteristics than standard golfers.

The demands of high-level golf have increased substantially over the last 20 years with elite golfer's travelling across the world to compete in prestigious tournaments for large amounts of money. It is vital that every element of a golfer's short and long-term preparation (including their warm-up pre play), allows them to perform to the highest levels of performance at all times.

The importance of appropriate levels of range of movement and flexibility at specific joints and soft tissues in order to perform the golf swing optimally has been well documented. However evidence is emerging that suggests while flexibility of musculoskeletal structures in certain parts of the body is important for the golf swing, the immediate effects of passive stretching has been linked with an immediate reduction in specific sports performance, in a variety of sports endeavors, including golf. It has been demonstrated that there is an immediate reduction in isometric strength immediately after passive stretching. Theoretical explanations for this acute decrease in performance include a less compliant muscle tendon unit (MTU), decreased neuromuscular reflex sensitivity, and neural inhibition attributable to the passive stretching. Interestingly, the amount of elastic energy that can be stored in the MTU is a function of the unit's stiffness. This stiffness and subsequent increase in elastic energy and force output can be increased through strengthening/activation of the muscle tendon unit.

An improvement in performance of the golf swing (including speed, accuracy and distance) has been shown when static stretching is eliminated and only active, dynamic stretches are performed during warm-up. Strength and resistance training can cause adaptive changes within the nervous system that allow a trainee to fully activate prime movers in specific movements and to better coordinate the activation of all relevant muscles, thereby affecting a greater net force in the intended direction of movement. Sale demonstrated an increase in peak force associated with both short and long term activation of prime movers, achieved via resistance training, as measured in a study utilizing electromyography. Although improving strength and flexibility following longer-term training has been shown to improve general elements of overall golf performance, no current research exists looking at the immediate effect of resistance training during warm-up on golf performance.

A warm-up can have many different effects on the body in order to prepare it for activity, ranging from raising the heart rate and increasing blood flow to tissues to facilitating nerve transmission and motor unit recruitment. There are many different strategies and techniques that can be used during a warm-up, and those chosen may vary depending on the demands of the sport for which an athlete is preparing.

At present the optimal warm-up procedure before golf to improve immediate performance during a maximal drive is unclear, but evidence suggests active dynamic stretching is better than static stretching. At present no studies have been carried out using elite golfers in order to assess the immediate performance benefits of muscle activation through resistance exercises. Therefore, the purpose of this study was to assess the effects of three different warm-up programs (active dynamic and two different combined active dynamic and resistance exercise programs) on immediate performance of a maximal golf drive.

**METHODS**

**Study Population**

Fifteen elite male competitive golfers (N=15) (professional or amateur with handicap below 2) between the ages of eighteen and forty were recruited through an opportunity sample of convenience and gave written informed consent to participate. Subjects were screened using eligibility and a medical questionnaire to meet the study criteria, which included having no current injuries, being in a stable training or competitive period, and were already involved in a regular strength and conditioning program. Of the 15 initial participants, 12 completed the study (N=12).
Two withdrew due to injury sustained outside of the study and one withdrew due to not being able to complete all 3 sessions in the 4 week time period.

**Study method**
The participants attended the study venue on three separate, non-consecutive days (max of 1 hr required at each session) over a maximum 4-week period at the Sheffield Hallam University Centre for Sports and Exercise Science Research laboratory. Medical screening questionnaires were completed for each participant at the start of each session. The set up for the exercises and collection of data was identical at each session for each participant. At every session there were two researchers present for safety and to have one person supervising the warm-up with the participant and one person carrying out data collection (blinded to the warm-up program) in order to reduce the chance of research bias. The participants randomly selected one warm-up program from three numbered cards and then carried out one of the three warm-up programs shown below, during each of the three sessions:

**Active Dynamic warm-up program. (AD)**
1. Ten practice swings with 1.13-kg weighted club (Momentus)
2. Three full-swing shots with sand wedge
3. Three full-swing shots with 8-iron
4. Three full-swing shots with 4-iron
5. Three full-swing shots with fairway metal wood
6. Three full-swing shots with driver

(Active Dynamic stretching warm-up progression with various golf clubs as used by Gergley)*

**Active Dynamic warm up program PLUS 10 minute functional resistance warm-up using Theraband® (FR).**
1. Theraband® (red) with rotational trunk movement in standing × 10 bilat
2. Theraband® (red) with standing lunge and rotational trunk movement × 10 bilat (see photo 1)
3. Theraband® (red) right arm cross chest adduction and internal rotation with body rotation × 10
4. Theraband® (red) left arm external rotation and shoulder abduction with rotation × 10
5. Theraband® (red) with wood chop from right and left trunk rotation × 10

Each exercise repeated × 2 sets

**Active dynamic warm-up program PLUS 10 minute linear based multi-joint strength program using weighted bar. (WT)**
1. Barbell dead lifts with 20 kg bar × 10
2. Barbell snatches with 15 kg bar × 10

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*Figure 1.*
3. Barbell squat with 20 kg barbell × 10 (see Photo 2)
4. Bench press with 20 kg Bench press × 10
5. Standing Bent over row with 20 kg barbell × 10

Each exercise repeated × 2 sets

The two different forms of resistance training programs used in this study have both been shown to have positive effects on strength and performance in golf and other sports when performed over longer periods of conditioning training. Linear multi-joint strengthening using weights was chosen for one resistance warm-up as theory suggests this creates a stiffening of the MTU to allow it to store elastic energy, which may help prepare the musculoskeletal system for the explosive power action of the golf swing. This type of training has also been used in other studies investigating the effect of longer term strengthening programs using key muscles/muscle groups involved in the golf swing, that have subsequently shown an improvement in overall golf performance as measured by handicap reduction. The functional resistance program was chosen as muscle recruitment provided by elastic resistance band exercises may result in improved performance through the activation of muscle recruitment patterns used in the golf swing as well as stiffening the MTU. Red theraband® was chosen as it was felt this strength of band would give sufficient resistance to create adequate activation of muscle recruitment patterns and stiffening of the MTU, without exerting high levels of resistance on the musculoskeletal system before a maximal effort golf swing, as may have happened if a stronger resistance band was used. The weight of bar and repetitions for the linear weight warm-up was selected for the same reasons.

Following completion of each warm-up routine the participant then went through their normal pre-shot routine as if they were preparing for competition and then hit ten maximum effort drives. Each of the ten drives was analyzed using Flightscope® radar technology (EDH, Orlando, Florida, USA, Kudo 2009 model). Participants had one minute rest intervals between each shot and were asked after each shot if they felt like it was a consistent ball strike (CBS), which was answered ‘yes’ or ‘no’ (see Appendix 1 for standard CBS protocol). Information relating to performance factors for each shot was collected via the Flightscope® for parameters including maximum club head speed (MCHS), maximum driving distance (MDD), smash factor (SF) and driving accuracy (DA). The performance factors measured are important pieces of information taken from the swing data, relating to the forces, control, and subsequent outcome that a golfer has over the golf club during a swing, as it contacts the ball, and over the ball’s final outcome after strike. Smash factor is the ratio between the ball speed and the club speed, it tells us about the centeredness of impact and the solidity of the shot, an important factor relating to performance. These particular factors were chosen as they were the ones used in previous studies and are the major performance factors and data relating to a maximal golf drive that are measured by equipment such as Flightscope® and used by professional golfers. No participants had performed any form of exercise in the 24 hours prior to each testing session. All participants agreed not to change their technique/golf swing between sessions and to use their same driver for each session. All participants used brand new Titliest™ Pro V1 balls for each shot at each testing session.

STATISTICS
All data analysis was performed using SPSS 19.0 software. All data input was repeated twice to reduce the chance of data input mistakes. A repeated-measures ANOVA test for 3 sample mean values was used to provide a statistical measure of actual mean difference between multiple applications. Paired t-tests were then performed between each of the three sets of data to identify within group differences between the data for each warm-up program.
RESULTS

Results of the repeated measures ANOVA test revealed a statistically significant ($p<0.05$) difference for the MDD ($p=0.042$), SF ($p=0.004$) and CBS ($p=0.004$) between the three warm-up programs (Table 1). No statistically significant differences were found between the warm-ups for MCHS and DA, however, the mean results did show improved figures for these two performance factors with the FR warm up. Paired t-tests between the three warm-up groups were used to further investigate the three factors of performance that showed statistically significant differences. Analysis showed that the functional resistance (FR) warm-up had increased MDD by 14.98 yards (+5.59%) over AD ($p=0.013$) and 12.98 yards (+4.81%) over the WT warm-up group ($p=0.05$). The SF for the FR warm-up was increased by 0.021 (+1.47%) compared to the AD ($p=0.003$) and by 0.01 (+0.69%) over the WT group ($p=0.011$). The CBS was increased in the FR group by 1.08 (+13.36%) over the AD warm-up group ($p=0.002$) and by 0.99 (+12.11%) over the WT group ($p=0.007$). No statistically significant differences were seen between the AD and WT warm-up programs for the MDD, SF and CBS.

DISCUSSION

The aim of this investigation was to identify if the addition of a resistance training program (FR or WT) to an active dynamic (AD) stretching program during the warm-up routine of elite golfers would result in improved golf performance in relation to maximum clubhead speed (MCHS), maximal driving distance (MDD), smash factor (SF), driving accuracy (DA) and consistent ball strike (CBS). The results revealed significant improvement in CBS, MDD and SF when a FR program is combined with an AD warm-up compared to an AD warm-up alone or when combined with a WT program during the warm-up. For the performance factors of DA and MCHS there were no significant differences between any of the three different warm-up groups. For the factors of MDD, CBS and SF there was no difference in performance seen between the AD and WT warm-up groups.

As there has been no previous research into performance of different resistance and stretching warm-ups on immediate golf performance it is difficult to draw comparisons to other studies. Strength training using both Theraband®-based functional resistance and weight based multi-joint methods over a longer period of weeks have been shown to have positive outcomes on strength and performance in golf, tennis and baseball.19-21 Tennis and baseball are both relatively comparable sports to golf in that they involve explosive power, swinging, and rotational movements. Both of these training methods have varying effects on the neuromusculoskeletal system but have created similar results in strength and performance improvement in certain sports. There is an increase in peak force associated not just from long-term activation of prime mover muscles through resistance training, but also in the immediate short term.13 However, the

<table>
<thead>
<tr>
<th>Warm Up Program</th>
<th>Maximum Clubhead speed (MCHS) (miles/hr) Mean</th>
<th>SD</th>
<th>Maximum driving distance (MDD) (yards) Mean</th>
<th>SD</th>
<th>Smash Factor (SF) Mean</th>
<th>SD</th>
<th>Driving accuracy (DA) (Yards from target) Mean</th>
<th>SD</th>
<th>Consistent Ball strike (CBS) (Yes - out of 10) Mean</th>
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<td>10.26</td>
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<td>0.004*</td>
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</table>

* Indicates statistically significant differences.
results of the current study suggest that performing a functional resistance warm-up program using Thera-band® had a statistically significant increase in MDD, CBS and SF during the performance of a maximal golf drive as compared to performing a linear multi-joint weight resistance program. Functional resistance training aims to enhance the coordinated working relationship between the muscular and nervous systems and the force-producing capabilities of a muscle group or motor pattern for a particular task. This may be a reason why activating functional movement and motor patterns involved in the golf swing during the FR warm-up in this study led to improvements in certain factors of the performance of a maximal golf drive, as opposed to the resistance based warm-up of the musculoskeletal system using weights in non functional movement patterns.

Performing sustained static stretches causes immediate reductions in performance of a maximal golf drive compared to when performing an active dynamic warm-up stretching program. Gergley suggested that “the skeletal muscles were normally and sufficiently innervated by the central nervous system but that less force was transferred to the golf club because of slack in the tendon following a static stretch”. In addition, altered neurological activity following the static stretch may have caused the skeletal muscles to fire without synchronization or adequate action potential, thus reducing coordination and/or force production, and that the transfer of force from the skeletal muscles to the golf club by the neurological system were temporarily impaired by the static stretching treatment. An explanation for the improvement in performance seen in this study by the addition of a FR program to an AD warm-up as opposed to an AD or WT program is that the stiffening of the MTU and task specific functional resistance exercises led to improved neurological activity of the skeletal muscles. This in turn may have resulted in greater coordination, force production, and performance of the golf swing in relation to CBS, MDD and SF.

Although no previous studies into the effects of strength training on immediate golf performance have been performed, the findings of this study are similar to that of other studies examining the effect of linear multi-joint resistance exercises on immediate performance of other activities, which showed no difference between active stretching, linear multi-joint high and low repetition and load exercises on standing jump and sprinting activities.

Based on the requirements of the golf swing and the physiological understanding of the musculoskeletal system and the results of this study, it would appear that a warm-up program should include activation of key rotational and stability muscle groups and motor patterns, as well as dynamic flexibility, in order to prepare the upper body, trunk and legs for explosive

| Table 2. Results of the paired samples t-test for Maximum Driving Distance (MDD) for each of the three warm ups. |
|---------------------------------|-----------------|-----------------|-----------------|-------------|-------------|
| | Paired Differences | 95% Confidence Interval of the Difference | Sig. (2-tailed) |
| Mean | Std. Deviation | Mean | Lower | Upper | t | df |
| Pair | MDD - ST theraband MDD |
| 2 | -2.09750 | -.785% | 9.36620 | 2.70379 | -8.04850 | 3.85350 | -.776 | 11 | .454 |
| 3 | +12.8741 | +4.81% | 20.38379 | 5.88429 | -.07708 | 25.82541 | 2.188 | 11 | .051 |

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power production. This may be achieved by stiffening the muscle tendon units (MTU), improving force output\(^{13}\) and enhancing neuromuscular response such as improved synchronization and more efficient muscle recruitment patterns\(^{26,27}\) with the use of functional resistance exercises. The current results showed that there were no statistically significant differences found between the MCHS and DA for any of the three warm-up groups, indicating that the addition of a resistance program to an active dynamic stretching warm-up had no effect on the performance of these two factors. Although no statistically significant difference was found for MCHS and DA factors of golf performance between the three groups, the FR warm-up group did produce better mean results for these factors than the other two groups (see Table 1). Depending on the effect required by the elite golfer on their performance those wishing purely to achieve optimum driving accuracy rather than greater driving distance may only wish to perform an active dynamic warm-up to optimize time spent doing a warm-up.

The golf swing is a closed kinetic chain activity occurring mainly in the transverse plane making it a unique skill and activity.\(^{28}\) A round of golf during professional competition can take in excess of 5 hours and involve long periods of inactivity followed by short periods of high intensity, explosive effort requiring a combination of power, flexibility, strength and skill. There are many other factors relating to performance in elite golf other than performing a maximal golf drive, such as the total score per round, putts per round, and external variations including the weather and equipment to name a few, which make it difficult to evaluate the effect of one particular intervention on overall golf performance in elite golfers. It is unknown from these findings what the latent effects of these warm-up programs are over longer time periods.

This study was specific to the immediate effects on performance of a maximal golf drive of elite male golfers between the ages of 18-40. Therefore, conclusions should not be drawn from the findings in relation to other sports or groups or aspects of performance relating to golf. Further research in this area is required on larger numbers and different groups in order to apply results to the wider population of golfers.

### RECOMMENDATIONS

The implications for physiotherapy practice from this study are that the warm-up strategies utilized immediately before golf are important and do have an effect on the immediate performance of a maximal golf drive. Given the large amount of prize money and pressures in professional golf every element of their preparation and performance is vitally important. Static stretching should be avoided as it has been shown to reduce immediate performance.\(^{4-10}\) Instead, functional resistance exercises utilizing rotational trunk movements (that mimic motor patterns and muscles used in the golf swing) when combined with AD exercises led to improved immediate performance of certain factors of the maximum golf drive compared to combined WT and AD or AD by itself. The results of this study will be incorporated into the daily physiotherapy practice of the author with elite golfers when helping them devise and carry out their warm-up programs. More research is required to identify the latent effect of these warm-up programs, the optimum duration of the warm-up, and the optimum components of the exercises such as repetitions, level of resistance, and the equipment used. Additionally, further research involving the use of these types of exercises in structured training programs over longer periods of time and their effect on performance would also be beneficial.

### CONCLUSION

Performing a combined AD and FR warm-up with Theraband\textsuperscript{®} leads to significant increase in immediate performance during the golf drive relating to maximal driving distance, smash factor, and consistent ball strike in elite male golfers as compared to performing an AD warm-up by itself or a combined AD with WT warm-up. No statistically significant difference was observed between the three warm-up groups when looking at immediate effect on driving accuracy or maximum club head speed. The addition of functional resistance activities to active dynamic stretching has immediate benefits to elite male golfers in relation to some factors of their performance.

### REFERENCES


ABSTRACT

Purpose/Background: Anterior knee pain (AKP), also known as patellofemoral pain syndrome (PFPS), is believed to be common in young, active females. A prevalence rate of 25% has been commonly cited in the literature. However, this rate may be more anecdotal than empirical. The purpose of this study was to estimate the prevalence of AKP in females 18 to 35 years of age.

Methods: Three cohorts of females, totaling 724 participants between 18 and 35 years of age participated in this study. The mean age of participants was 24.17 years (SD: 2.34), mean height was 165.10 cm (SD: 7.26), mean weight was 65.46 kg (SD: 14.10), and mean BMI was 23.95 kg/m2 (SD: 4.86). Participants completed the Anterior Knee Pain Questionnaire (AKPQ), a functional outcome tool developed to document symptoms of AKP and progress in patients during rehabilitation.

Results: The mean score on the AKPQ for the left lower extremity was 93.38 (SD: 10.00) and 93.16 (SD: 11.37) for the right lower extremity. Using a cutoff score of 83 on the AKPQ, 85 of 724 subjects were classified as having AKP in the left lower extremity for a prevalence of 12% (95% CI = 9%-14%) while 94 subjects were classified with AKP in the right lower extremity for a prevalence of 13% (95% CI = 11%-15%).

Conclusion: The estimated prevalence of AKP in this sample of 18-35 year old females of 12-13% is much less than the commonly cited value of 25%. The results may provide a better representation of subjects with AKP.

Key Words: Anterior knee pain, Anterior Knee Pain Questionnaire (AKPQ), functional limitations, prevalence

Level of Evidence: 3
INTRODUCTION
Anterior knee pain (AKP) or patellofemoral pain syndrome (PFPS) has been described as a common diagnosis among young, active females.1,2 The terms AKP and PFPS are often used synonymously to describe a syndrome, that includes pain in the anterior part of the knee that can result from patellar dislocation, patellar subluxation or, on occasion, no trauma.3,4,5 The diagnosis of AKP is usually determined by the patient's report of symptoms, rather than any combination of clinical or functional tests.

Prevalence is defined as the number of cases of a condition existing in a population at a given time divided by the number of individuals in a given population.6 The prevalence of AKP has been reported as between 15-45% of the population.7 Callaghan and Selfe,3 in a review article, noted that there is a wide variation in the reported prevalence of AKP, and that these estimates are based primarily on patients in the military or patients consulting practitioners at sports medicine facilities. They concluded that existing estimates of the AKP prevalence are inadequate, and that “the incidence of patellofemoral pain syndrome in the general population has not been evaluated and there clearly is a need for a study on the incidence of patellofemoral pain syndrome.”(3, p. 41)

There are no known valid clinical tests for AKP or PFPS at this time.7,8 Individuals with the condition are most typically identified by ruling out other conditions,9 by their history, as well as reporting the functional abilities as assessed by the Anterior Knee Pain Questionnaire (AKPQ).10 The AKPQ is a functional outcome tool developed to document symptoms of AKP and chart progress in patients during their rehabilitation.10 It includes thirteen questions that query the patient about their ability to perform a number of different activities, as well as a question about pain. It is considered a valid and reliable tool that is easy for patients or subjects to complete.11,12

The purpose of this study was to estimate the prevalence of AKP in females 18 to 35 years of age.

METHODS
Sample
This study was approved by the Institutional Review Board (IRB) of Arizona State University and A. T. Still University-Mesa. All subjects participating in this study were required to sign an informed consent agreement prior to participation. The sampling plan was designed to yield data from a wide variety of female participants aged 18 to 35. Data were collected from three cohorts. The first cohort included 310 female subjects between the ages of 18 and 23 years of age; the second, 165 females between 25 and 35 years of age; and the third, 249 females between 25 and 35. Subjects in the first and third cohorts were nulliparous and not currently pregnant. Subjects in the second cohort had delivered between 1 and 3 children, were not currently pregnant and were at least 1-year post-partum. The total sample for the study included 724 females between 18 and 35 years of age.

Data Collection and Analysis Procedures
Participants' age, height, and weight were measured and recorded. They then completed the AKPQ, based on their current symptoms and functional abilities. A cutoff of 83 on the AKPQ was chosen to identify those individuals with anterior knee pain, following the recommendations made in the study by Kujala et al.10 To substantiate the cutoff point further, the authors of the current study analyzed the Receiver Operating Characteristic (ROC) curve for AKPQ reported in a therapeutic intervention program conducted by Crossley et al11 using the NIH Image J software program (NIH, NIH, Bethesda, Md) to determine the area under the curve for the plotted data. The cutoff point chosen by Crossley et al did not appear to optimally balance the sensitivity and specificity of the AKPQ.11 The area under the curve for the AKPQ, based on the current re-analysis, was approximately .88. The authors used formulas derived from Akobeng13 and determined that the cutoff point for the AKPQ approximated 83.

Descriptive statistics for age, height, weight and body mass index (BMI) for the different cohorts were calculated. Means and standard deviations for the reported scores on the AKPQ were also calculated for the cohorts. The number of subjects who were considered to be positive for AKP as determined by the AKPQ was counted. The prevalence was then calculated as the number of cases divided by the total number of subjects in the various samples and the total population in the study. A 95% Confidence Interval of the prevalence was calculated for each cohort as well as for the sample as a whole.
RESULTS
The descriptive statistics for each cohort and the sample as a whole can be found in Table 1. The first cohort consisted of 376 subjects with a mean age of 20.41 years (SD: 1.88), mean height of 164.99 cm (SD: 6.98), mean weight 64.25 kg (SD: 13.33), and mean BMI of 23.58 kg/m² (SD: 4.55). The mean score on the AKPQ for the left lower extremity (LE) was 93.80 (SD: 8.93), mean score for the right LE was 93.72 (SD: 11.61), and mean score for both LE’s was 93.76 (SD: 10.35).

The second cohort consisted of 165 subjects with a mean age of 30.40 years (SD: 2.98), mean height of 164.06 cm (SD: 6.73), mean weight 67.69 kg (SD: 15.15), and mean BMI of 25.21 kg/m² (SD: 5.00). The mean score on the AKPQ for the left LE was 93.24 (SD: 10.64), mean score for the right LE was 93.45 (SD: 10.06), and mean score for both LE’s was 93.34 (SD: 10.34).

The third cohort consisted of 228 subjects with a mean age of 27.78 years (SD: 4.03), mean height of 164.97 cm (SD: 7.50), mean weight 65.84 kg (SD: 13.75) and mean BMI of 24.18 kg/m² (SD: 4.73). The mean score on the AKPQ for the left LE was 92.29 (SD: 11.26), mean score for the right LE was 90.92 (SD: 12.69), and mean score for both LE’s was 91.60 (SD: 11.99).

For the entire sample of 769 subjects, the mean age was 24.74 years (SD: 1.89); mean height was 164.78 cm (SD: 7.09), mean weight was 65.46 kg (SD: 12.36) and mean BMI of 24.11 kg/m² (SD: 4.70). The mean score on the AKPQ for the left LE was 93.38 (SD: 10.00) mean score for the right LE was 93.16 (SD: 11.37), and mean score for both LE’s was 93.27 (SD: 10.63). Most of the subjects had some sort of mild dysfunction although not at the threshold to be classified with AKP.

For the first cohort, 32 subjects reported positive scores for AKP on the left LE, 37 on the right LE, and 69 on both LE’s. For the second cohort, 26 subjects reported positive scores for AKP on the left LE, 25 on the right, and 51 on both LE’s. For the third cohort, 27 subjects reported positive scores for AKP on the left LE, 32 on the right, and 59 on both LE’s. For all subjects, 85 subjects reported positive scores for AKP on the left LE, 94 on the right, and 179 on both LE’s. A count of the subjects who were classified as positive and negative as well as the calculated prevalence and the 95% confidence intervals can be found in Table 2.

DISCUSSION
Baquie and Brukner stated that PFPS was the most common complaint in physically active patients consulting their physicians. Fredericson et al noted that PFPS is one of the most common disorders of the knee, accounting for 25% of all knee injuries treated in sports medicine clinics. Many authors have reported prevalence rates of around 25%. Callaghan and Selve conducted a literature review in order to describe the different prevalence and incidence rates for patellofemoral pain syndrome or anterior knee pain that have been reported in numerous articles. For the most part, Callaghan and Selve found that the reported prevalence was often anecdotal. Many authors have simply reported that PFPS is “common,” “frequent,” or “prevalent.”

Devereaux and Lachman reported that 25% of the patients in their sports injury clinic had patellofemoral arthralgia. Boling et al reported a prevalence of 15% for AKP among female cadets at the United States Naval Academy, and an incidence of 33/1000 person-years. Wills et al reported an incidence rate of 8.75% for AKP among military trainees; whereas,

<table>
<thead>
<tr>
<th></th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>All Subjects</th>
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<tr>
<td>Count</td>
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<td>165</td>
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<td>Age (yrs)</td>
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<td>25.21 (5.00)</td>
<td>23.46 (4.38)</td>
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</table>
Harrison and Magee\textsuperscript{24} reported incidence rates between 10-40% for AKP. Studies conducted with sequestered samples such as individuals participating in military service may not be reflective of the actual demographics of the larger population.

AKP is differentially distributed across genders, with greater prevalence in females than males. Dehaven and Linter\textsuperscript{25} reported that 33% of females complained of patellofemoral pain syndrome. Fairbank et al\textsuperscript{26} determined that 69 of 219 (32%) of girls between 13 and 17 years presented with anterior knee pain. Witzvrouw et al\textsuperscript{27} found that 13 of 131 (10%) of female, physical education students had patellofemoral pain syndrome, with 11 subjects exhibiting symptoms bilaterally. Tauton et al\textsuperscript{28} noted that 62 of 207 (30%) of female runners reported symptoms of AKP that required consultation with their physician. Boling et al\textsuperscript{22} found that females were 2.23 times more likely to develop AKP than males. The authors of the current study chose to limit the current investigation to only females. Studies of functional limitations in males due to AKP are needed.

The medical diagnosis of AKP has historically included many different conditions, ranging from non-traumatic anterior knee pain with a duration of greater than 6 weeks\textsuperscript{24} to chondromalacia patellae.\textsuperscript{19,27,33} Perhaps a functional diagnosis as offered by the AKPQ would be better than a medical diagnosis when treating patients with AKP. Several authors have found little to no validity for the common clinical tools used to assess individuals with AKP.\textsuperscript{7,8,9,31} Furthermore, the diagnosis is usually made by ruling out other conditions.\textsuperscript{9} Therefore, outcome tools such as the AKPQ may be better suited to document symptoms and chart progress in patients during their rehabilitation.\textsuperscript{10,11,29} To do so would require that the outcome tools receive better scrutiny for validity, with defensible receiver-operating characteristics (ROC) curves. Justifiable cutoff points for any tool developed then need to be established to truly discriminate between those patients with the condition and patients without.

A delimitation of this study is the fact that the sample was recruited from a large metropolitan area in the Southwestern United States. A limitation of the study

<table>
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<th>Number of positives for AKP</th>
<th>Number of negatives for AKP</th>
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<td>.13</td>
<td>.11 - .15</td>
</tr>
<tr>
<td>Both</td>
<td>93.27 (10.63)</td>
<td>179</td>
<td>1269</td>
<td>.12</td>
<td>.11 - .14</td>
</tr>
</tbody>
</table>

\* 95% confidence interval

\begin{table}[h]
\centering
\begin{tabular}{|l|c|c|c|c|c|c|}
\hline
\textbf{} & \textbf{Mean (SD) score for AKPQ} & \textbf{Number of positives for AKP} & \textbf{Number of negatives for AKP} & \textbf{Prevalence} & \textbf{95% CI*} \\
\hline
\textbf{Group 1} & & & & & \\
Left & 93.80 (8.93) & 32 & 278 & .10 & .07 - .14 \\
Right & 93.72 (11.61) & 37 & 273 & .12 & .10 - .14 \\
Both & 93.76 (10.35) & 69 & 551 & .11 & .10 - .12 \\
\hline
\textbf{Group 2} & & & & & \\
Left & 93.24 (10.64) & 26 & 139 & .16 & .10 - .21 \\
Right & 93.45 (10.06) & 25 & 140 & .15 & .10 - .21 \\
Both & 93.34 (10.34) & 51 & 279 & .15 & .12 - .19 \\
\hline
\textbf{Group 3} & & & & & \\
Left & 92.29 (11.26) & 27 & 222 & .11 & .07 - .15 \\
Right & 90.92 (12.69) & 32 & 217 & .13 & .09 - .17 \\
Both & 91.60 (11.99) & 59 & 439 & .12 & .09 - .15 \\
\hline
\textbf{All Subjects} & & & & & \\
Left & 93.38 (10.00) & 85 & 639 & .12 & .09 - .14 \\
Right & 93.16 (11.37) & 94 & 630 & .13 & .11 - .15 \\
Both & 93.27 (10.63) & 179 & 1269 & .12 & .11 - .14 \\
\hline
\end{tabular}
\caption{Mean scores (standard deviations) for the AKPQ, counts of positive and negative scores and prevalence with 95% confidence intervals.}
\end{table}
was the AKPQ was used as the functional outcome tool. The AKPS was chosen because the reported validity and reliability for the test were deemed adequate. The AKPQ has been criticized because it does not address the patient's ability to kneel, which is a commonly impaired functional activity in those with AKP. However, it is easy to administer and subjects have reported that it was easy to complete. Crossley et al recommended that a Visual Analog Scale be administered to individuals when screening for AKP. However, the AKPQ includes a section on pain; therefore, the authors of the current study deemed it unnecessary to use either the Visual Analog Scale or the Numeric Rating Scale for pain during data collection.

CONCLUSION

The overall prevalence rate of anterior knee pain for females in the general population was .12. It appears the reported prevalence of AKP in many studies may have been overestimated or anecdotal. The results of the current study may provide better representation of subjects who exhibit functional limitations or disabilities associated with AKP. As there are no valid clinical tools for diagnosing AKP, and a diagnosis of AKP is usually made by ruling out other conditions, clinicians use functional outcome tools for identifying individuals with AKP.

REFERENCES

20. Heino Brechter J, Powers CM. Patellofemoral stress during walking in persons with and without...


ABSTRACT

Purpose/Background: The purpose of this study was to systematically review the literature for functional performance tests with evidence of reliability and validity that could be used for a young, athletic population with hip dysfunction.

Methods: A search of PubMed and SPORTDiscus databases were performed to identify movement, balance, hop/jump, or agility functional performance tests from the current peer-reviewed literature used to assess function of the hip in young, athletic subjects.

Results: The single-leg stance, deep squat, single-leg squat, and star excursion balance tests (SEBT) demonstrated evidence of validity and normative data for score interpretation. The single-leg stance test and SEBT have evidence of validity with association to hip abductor function. The deep squat test demonstrated evidence as a functional performance test for evaluating femoroacetabular impingement. Hop/Jump tests and agility tests have no reported evidence of reliability or validity in a population of subjects with hip pathology.

Conclusions: Use of functional performance tests in the assessment of hip dysfunction has not been well established in the current literature. Diminished squat depth and provocation of pain during the single-leg balance test have been associated with patients diagnosed with FAI and gluteal tendinopathy, respectively. The SEBT and single-leg squat tests provided evidence of convergent validity through an analysis of kinematics and muscle function in normal subjects. Reliability of functional performance tests have not been established on patients with hip dysfunction. Further study is needed to establish reliability and validity of functional performance tests that can be used in a young, athletic population with hip dysfunction.

Level of Evidence: 2b (Systematic Review of Literature)

Key Words: Functional Testing, hip, reliability, validity

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INTRODUCTION

Over the past decade, physical therapists have adopted the International Classification of Functioning, Disability, and Health (ICF) model\(^1\) to evaluate and treat patients of all levels of health and disability. The ICF model encourages assessment of patients, including athletes, within the context of their function. Therefore, an athlete, or a subject that is regularly participating in an organized sport activity or training, should be evaluated with consideration of the physical demands relative to their sport-related activities. Current evaluation procedures for the hip including range of motion (ROM), strength, and special tests are intended to identify a specific pathology or impairment,\(^2\) not necessarily to identify dysfunction. Dysfunction can be defined as pain, asymmetry, or injury that impairs normal movement and performance of a functional activity. Clinicians need to understand which sport-specific functional performance tests can best be used to identify and treat hip dysfunction of an athlete.\(^3\)

Functional performance tests require the integration of multiple body regions and systems to execute movement patterns and therefore may have an advantage over more traditional clinical measures. Components of ROM, flexibility, muscular strength, endurance, coordination, balance, and motor control of multiple regions can be assessed simultaneously by observing the movement patterns in which the athlete normally functions.\(^4,5,6\) Functional performance tests have been commonly used to identify impairments related to ankle\(^7-15\) or knee injuries\(^16,17,18,21\) and determine the readiness of an athlete to return to sports after injury.\(^22\) Similar information has not been established for the hip. Although athletes with hip dysfunction are commonly encountered in a sports medicine rehabilitation setting, currently it is unclear which functional performance tests are most appropriate to use in this population.

To help clinicians employ appropriate functional performance tests in the evaluation of hip dysfunction, the evidence for reliability and validity of the functional performance tests should be considered. Reliability describes how well the test can be reproduced under the same conditions. Validity describes how well a test measures what it is intended to measure. The population in which the evidence for reliability and validity of a functional performance test is established is also an important consideration. Evidence of reliability and validity should be established among a sample of subjects that are similar to the population of patients for which the test is to be used.\(^24\) Clinicians need to determine which functional performance tests are valid and reliable for use during evaluation of athletes with hip dysfunction. The purpose of this systematic review was to examine current evidence for reliability and validity of functional performance tests used in a young, athletic population with hip dysfunction.

METHODS

Search Strategy

An electronic search of PubMed and SPORTDiscus databases were performed for the purpose of identifying peer-reviewed articles that utilized functional performance tests to assess function of the hip joint and related structures. The following key words were used in combination for the search of the respective databases: “functional” AND “test”, OR “measure”, OR “assessment”, OR “screen”, AND “lower extremity” OR “hip”. The primary author reviewed the abstracts of the articles identified from the database searches and duplicate studies were removed. The full text articles describing a functional performance test related to the hip joint were retrieved for data extraction and the references reviewed for additional articles of interest. In addition, the individual names of the identified functional performance tests including the deep squat, single-leg squat, single-leg balance, Star Excursion Balance Test, Balance Error Scoring System, Functional Movement Screen\(^\text{TM}\), single leg hop, triple hop, side hop, timed hop, medial hop, lateral hop, figure 8 hop, cross-over hop, square hop, agility T-test, modified agility T-test, and reactive agility tests were searched independently to provide a comprehensive list of functional performance tests used for patients with hip dysfunction.

Study Selection Criteria

Studies were included if the following criteria were met: 1) written in English 2) published in a peer-reviewed journal from 1990-present, and 3) described the use of a functional performance test in the assessment of ROM, strength, balance, postural control, or athletic performance of the lower extremity. Excluded
studies were those that described patient self-report measures, targeted an elderly population (>60 years of age), or if the functional performance test was performed on subjects with neurological involvement caused by cerebral palsy, a cardiovascular accident, or head injury.

**Data Extraction**

**Grouping of Functional Performance Tests**

Functional performance tests were grouped into one of four categories: 1) movement 2) balance, 3) hop/jump, or 4) agility. A movement test was defined as a quantitative or qualitative measure of the subject's ability to perform a specific motor pattern with control, precision, and symmetry. Tests of balance measured the patient's ability to maintain balance and postural control under different conditions. Hop/jump tests assessed the quality and/or quantity of tasks related to propulsion and/or absorbing impact. Agility tests assessed the subject's ability to run, cut, pivot, and/or change direction through a predetermined course.

**Evidence of Reliability**

Statistical evidence for test-retest, intra-rater, or inter-rater reliability was recorded as it was originally reported in the identified articles. This included intra-class correlation coefficients (ICC) for interval data or a kappa statistic for ordinal and normative data. An ICC or Kappa statistic can range from 0.0 to 1.0. An ICC or Kappa statistic greater than or equal to .75 are considered excellent, .40 to .74 are moderate, and less than .40 are considered poor. Test-retest reliability refers to the agreement of two separate trials of the same test by a single investigator. Intra-rater reliability is the agreement of a singular testing session by single investigator. This is usually established through videotaped recordings of a singular testing session. Inter-rater reliability is the agreement of the same test by two separate investigators. Intra-rater reliability and test-retest reliability are similar and often referred interchangeably in the literature. There is, however, an important distinction between the intra-rater and test-retest reliability. Intra-rater reliability isolates intra-rater error as the same performance is evaluated on two separate occasions (i.e. a single evaluator watches the videotape and grades a single test performance two separate times). Test-retest reliability also accounts for intra-rater error in addition to the variability of performance on two separate testing sessions (i.e. a single evaluator grades the performance of subjects performing a functional performance test on two separate occasions). Test-retest reliability more closely represents how functional performance tests may likely be employed in a clinical environment. The authors of the original articles reviewed for this analysis may not have intended to imply the terminology as defined above. Therefore, when reporting reliability the terminology consistent to that reported in the original article was used.

**Evidence of validity**

Evidence of validity of a functional performance test can be established by demonstrating its relationship to subjects with a known dysfunction of the hip joint. Such a relationship may be expressed as a value of sensitivity or specificity in detecting the presence of dysfunction. Validity may also be established by a relationship, expressed statistically by a correlation coefficient, to other variables of hip function. For instance, a relationship of a functional performance test to ROM or strength values of the hip joint may offer evidence of validity to a functional performance test.

**Evidence of score interpretation**

Evidence for score interpretation was also extracted when available. This included normative values as well as the smallest detectable difference (SDD) or the minimal detectable change (MDC) as reported in the original article. The SDD and MDC are often described interchangeably and represent the change or difference between test scores that distinguish error from true changes in the measurement.

**RESULTS**

The search results consisted of 18 articles describing movement tests, 24 articles describing balance tests, 26 articles describing hop/jump tests, and 6 articles describing agility tests as shown in Figure 1. Review of the articles revealed four functional performance tests that demonstrated evidence of validity. This included two movement tests (the deep squat test and single-leg squat test) and two balance tests (single leg stance test and Star Excursion Balance Test). The deep squat was the only functional
performance test that was performed on subjects with hip dysfunction. They demonstrated less squat depth and altered lumbo-pelvic kinematics compared to healthy controls. The single leg squat, single-leg stance, and the Star Excursion Balance Test (SEBT) were functional performance tests that demonstrated evidence of validity through a relationship to hip abductor muscle function. Subjects graded as “poor” on the single leg squat test exhibited weaker and slower muscle activation of the hip abductors than those graded as “good”. Provocation of pain during 30-second single-leg stance had high sensitivity (100%) and specificity (97.3%) in detecting tendinopathy of the gluteus medius and minimus. For the SEBT, posterior-medial and posterior-lateral reach distances of the SEBT have been correlated to hip abduction and extension strength (r = .48 - .51), and the medial reach of the SEBT elicited activation of the gluteus medius at 49% of maximal volitional isometric contraction. The SEBT also demonstrated a relationship
to hip ROM. Hip flexion ROM was shown to explain a high percentage of variance (92-95%) in SEBT scores. Table 1 summarizes the evidence of validity for the use of functional performance tests in subjects with hip dysfunction. There was no evidence of validity for hop/jump or agility tests for patients with hip dysfunction.

None of the functional performance tests demonstrated evidence of reliability in a population of young, athletic patients with hip dysfunction. However, evidence of reliability for functional performance tests in healthy subjects with normative values for score interpretation was identified in 2 movement, 4 balance, 11 hop/jump, and 3 agility tests (Table 2). Ten of these functional performance tests also had established SDD or MDC values on healthy subjects. This information is summarized in Table 2. The authors from a majority of the articles reported moderate to excellent reliability (.61-1.00) of the functional performance tests in groups of healthy subjects. The single leg squat, single leg balance, and star excursion balance test, however, had conflicting evidence of reliability with some reports suggesting poorer reliability (.21-.58) of these specific functional performance tests.

DISCUSSION

The primary purpose of this study was to systematically review the literature for evidence of reliability and validity of functional performance tests used with a young, athletic population with hip dysfunction. The single-leg stance test, deep squat test, single-leg squat test, and SEBT demonstrated evidence of validity to be used in a population of patients with suspected hip dysfunction. The evidence for validity suggests that gluteal tendinopathy and function of the hip abductors may be assessed with the single-leg stance test,30 single-leg squat test,28,29 and SEBT.32,33 The deep squat test demonstrated evidence of validity as a functional performance test for evaluating patients with suspected FAI.27 Additionally, there were 20 tests that had evidence of reliability in healthy subjects with normative data provided to aide in score interpretation. Clinicians may use this normative data to identify impairments of patients with hip dysfunction that score outside the normal range of healthy subjects on the functional performance tests.

The authors of the current systematic review aimed to identify existing functional performance tests that demonstrated evidence for validity in a population of young, athletic patients with hip dysfunction. Only
Table 2. Evidence of Reliability and Normative Values for Functional Performance Tests in Physically Active Subjects.

<table>
<thead>
<tr>
<th>Test</th>
<th>Category</th>
<th>Average age of subjects</th>
<th>Evidence of Reliability</th>
<th>Normative values for Healthy Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Leg Squat Test</td>
<td>Movement</td>
<td>24 ± 5 years ²⁹</td>
<td>.61 - .80 (intra-rater)²⁹</td>
<td>&quot;Good&quot; to &quot;Excellent&quot; alignment of hip flexion (&lt;65°), hip adduction (&lt;10°) and knee valgus (&lt;10°)²⁹</td>
</tr>
<tr>
<td>Functional Movement Screen</td>
<td>Movement</td>
<td>22 ± 4 years ¹⁷</td>
<td>.97 (inter-rater)³⁷</td>
<td>15-16 composite score ³⁷</td>
</tr>
<tr>
<td>Single Leg Balance Test (Trendelenberg Test)</td>
<td>Balance</td>
<td>33 ± 11 years (males) ²⁷; 28 ± 8 years (females) ⁴⁶</td>
<td>.58 (intra-rater)³⁶ MCD =4° of pelvic on femoral angle ³⁶</td>
<td>Normal pelvic on femoral angle = 83° (range:76-94°)³⁶</td>
</tr>
<tr>
<td>Single Leg Balance (10 second Balance Test with eyes closed)</td>
<td>Balance</td>
<td>21 ± 2 years (males) ²⁸; 28 ± 8 years (females) ⁴⁸</td>
<td>.21 (test-retest)⁴⁸ 1.00 (inter-rater)⁴⁸</td>
<td>Maintain postural control and balance on a single limb with eyes closed for 10 seconds⁴⁸</td>
</tr>
<tr>
<td>Balance Error Scoring System</td>
<td>Balance</td>
<td>21 ± 2 years (males) ²⁸; 28 ± 8 years (females) ⁴⁸</td>
<td>.74 (test-retest)⁴⁸ SDD= 9.4 errors (inter-tester) ⁷.3 errors (intra-tester)⁴⁹</td>
<td>9.1 errors - female gymnasts 14.1 errors - female basketball players ⁴⁰ 5-7 errors – male baseball players ³¹</td>
</tr>
<tr>
<td>Star Excursion Balance Test</td>
<td>Balance</td>
<td>22 ± 3 years (males) ²³; 23 ± 3 years (females) ³²</td>
<td>.84-92 (test-retest)³² .35-93 (inter-rater)³³ SDD= 6-8% of the subject’s limb length ³³</td>
<td>Anterior reach difference &lt; 4 cm &gt;94% of composite score ³⁷</td>
</tr>
<tr>
<td>Single Leg Hop</td>
<td>Hop/Jump</td>
<td>23 ± 3 years (males) ²³; 22 ± 4 years (females) ⁴¹; 25 ± 4 years ³⁴</td>
<td>.80-96 (test-retest)³² ⁵⁴ SDD= 22% of the subject’s limb length ³³</td>
<td>Females=157% of leg length Males=189% of leg length ³³</td>
</tr>
<tr>
<td>Triple Hop</td>
<td>Hop/Jump</td>
<td>23 ± 3 years (males) ²³; 22 ± 4 years (females) ⁴¹; 25 ± 4 years ³⁴</td>
<td>.80-95 (test-retest)³² ⁵⁴ SDD: Females= 48% of leg length Males= 64% of leg length ³³</td>
<td>Females= 505% of leg length Males= 585% of leg length ³³</td>
</tr>
<tr>
<td>Timed Hop Test</td>
<td>Hop/Jump</td>
<td>23 ± 3 years (males) ²³; 22 ± 4 years (females) ⁴¹; 25 ± 4 years ³⁴</td>
<td>.60 -.84 (test-retest)³² ⁵⁴ SDD: Females=.21 seconds Males=.23 seconds ³¹</td>
<td>Females= 2.06 seconds Males=1.76 seconds LSI &gt; 99%³³</td>
</tr>
<tr>
<td>One-legged Hop Test (Medial and Lateral)</td>
<td>Hop/Jump</td>
<td>Male hockey players 20± 3 years ³⁵</td>
<td>.87-95 (test-retest)⁵⁵</td>
<td>Medial=157 cm and Lateral=160 cm for male hockey players ²% difference between medial and lateral distances ³⁵</td>
</tr>
<tr>
<td>Side Hop Test (Timed Test)</td>
<td>Hop/Jump</td>
<td>female athletes 22± 2 years ³⁶; college students 20± 2 years ³⁶</td>
<td>.48-.84 (test-retest)³⁶ ⁵⁶ MDC=5.82 seconds ⁵⁶</td>
<td>Females=8.20 seconds Males=7.36 seconds ³⁶</td>
</tr>
<tr>
<td>Side Hop Test (Number in 30 seconds)</td>
<td>Hop/Jump</td>
<td>Male and female 28± 4 years ³⁸</td>
<td>.87 – 93 (test-retest)³⁸</td>
<td>50 hops ³⁸</td>
</tr>
<tr>
<td>Figure 8 Hop Test</td>
<td>Hop/Jump</td>
<td>female athletes 22± 2 years ³³; college students 20± 2 years ³⁶</td>
<td>.85-99 (test-retest)³³ ⁵⁶ MDC=4.59 seconds ⁵⁶</td>
<td>Females=12.47 seconds Males=11.36 seconds LSI ≤ .81 seconds ³³</td>
</tr>
<tr>
<td>The Cross-Over Hop Test (for time)</td>
<td>Hop/Jump</td>
<td>college students 20± 2 years ³⁶</td>
<td>.96 (test-retest) MDC=1.03 seconds ³⁶</td>
<td>2.7-2.8 seconds ³⁶</td>
</tr>
<tr>
<td>The Cross-Over Hop Test (for distance)</td>
<td>Hop/Jump</td>
<td>23 ± 3 years (males) ²³; 22 ± 4 years (females) ⁴¹; 25 ± 4 years ³⁴</td>
<td>.86-96 (test-retest)³³ ⁵⁴ SDD=55-59% of the subject’s leg length ³³</td>
<td>Females= 480% of leg length Males=555% of leg length ³³</td>
</tr>
<tr>
<td>Square Hop Test (for time)</td>
<td>Hop/Jump</td>
<td>college students 20± 2 years ³⁶</td>
<td>.90 (test-retest) MDC=3.88 seconds ³⁶</td>
<td>15 – 16 seconds ³⁶</td>
</tr>
</tbody>
</table>
the single-leg stance test and deep squat test had evidence of validity in patients with confirmed hip dysfunction. The single-leg stance test was performed on subjects with greater than 4 months of lateral hip pain. Provocation of pain during 30 seconds of single leg stance had high sensitivity (100%) and specificity (97.3%) in detecting tendinopathy of the gluteus medius and minimus confirmed by magnetic resonance imaging (MRI). Based on the current evidence, the single-leg stance test has clinical value in ruling out other potential sources of lateral hip pain including lumbosacral, sacroiliac, or intra-articular pathology from gluteal tendinopathy, otherwise known as greater trochanteric pain syndrome (GTPS). The deep squat test was performed on subjects with radiologically confirmed FAI. The maximal squat depth in subjects with FAI (41% of leg length) was significantly less when compared to healthy controls (32% of leg length). Clinicians may test maximum squat depth in patients with suspected FAI to help confirm a diagnosis of FAI. Further studies are needed to determine how the single-leg stance and deep squat tests may compliment current clinical exam procedures to identify the presence of specific hip dysfunction.

While the single-leg stance and deep squat tests provided evidence of validity in subjects with hip dysfunction, the SEBT and single-leg squat test provided evidence of validity through an analysis of kinematics and muscle function in normal subjects. Three studies have related SEBT performance to kinematic and muscle function variables of the hip joint. Hip flexion range of motion was shown to explain a high percentage of variance (92-95%) in SEBT performance. Electromyographic study of the gluteus medius demonstrated the medial reach of the SEBT elicited the gluteus medius at 49% of maximal volitional isometric contraction. Hip abduction and extension strength also demonstrated a moderate correlation (r = .48 - .51) to posterior-medial and posterior-lateral reach distances of the SEBT. The moderate correlation implies that gluteal muscle strength only partially accounts for the variance of SEBT scores. The single-leg squat also demonstrated a relationship to hip abductor muscle function. However, the strength of this relationship has been disputed. DiMattia et al. reported poor association (r = .21) of the single-leg squat to hip abductor strength. The SEBT and the single-leg squat test have not been studied on a population of patients with hip dysfunction, but may have value to help clinicians screen for ROM and muscle strength impairments. ROM and strength deficits are commonly associated with hip pathology including FAI, osteoarthritis, or GTPS. A positive finding or asymmetry on the SEBT or single-leg squat test may lead the clinician to perform goniometry or dynamometry to further objectify ROM and strength deficits observed during the functional performance tests.

The reliability of a test is important to be able to confidently interpret the results. There were 2 movement, 4 balance, 11 hop/jump, and 3 agility tests with evidence of reliability in a young, healthy population. The Functional Movement Screen™ (FMS) is a series of seven individual movement tests that have been reliable in screening and evaluating athletes. Each test is graded on an ordinal scale based on the ability of the subject to perform specific motor func-
The FMS™ is designed to be a comprehensive cross section of functional movement and has been used to predict an athlete's risk for non-specific injury. The FMS™ is an intriguing tool for patients with varied hip dysfunction as it tests multiple movement patterns that require different components of hip ROM, strength, and trunk control. Such tests may elicit familiar symptoms or indicate impairments related to FAI, labral tears, osteoarthritis, or GTPS. Clinicians may use normative data established for the FMS™ as a guide to identify abnormal findings on the FMS™ for patients with hip-related dysfunction. Further study is needed to determine if the FMS™ is able to accurately predict hip-specific injuries.

Similar to the FMS™, hop/jump tests also demonstrated good to excellent reliability in normal subjects. Hop tests have also shown ability to discriminate injured from uninjured lower extremities, particularly in the assessment of ankle instability and post-operatively following ACL reconstruction. Researchers have established normative, gender-specific values for hop tests in young, athletic subjects. These values may serve as benchmarks that may be helpful in interpreting an “abnormal” score for a subject with hip-related dysfunction. Field agility tests have demonstrated evidence of good reliability, but have not been able to discriminate injured versus uninjured limbs in the same manner as hop tests. This is likely because agility tests require bipedal movement. However, agility tests may have value in an athletic population as the tests may more closely mimic the dynamic requirements of sport activity. The reliability of hop/jump and agility tests measures have not been established on patients with hip dysfunction. It remains unclear how patients with hip dysfunction perform on these tests without further study. For patients with unilateral hip symptoms, hop tests may be used in comparison of the uninvolved side. Interpretation of agility test results is limited to a comparison of scores established on healthy subjects. Whether jump/hop tests or agility tests can be used to discriminate subjects with hip-related dysfunction remains unknown.

There are limitations of this systematic review that should be acknowledged. First, the authors established very specific inclusion/exclusion criteria for selection of functional performance tests included in this review. This included only exploring functional performance tests for a young and athletic population. Many tests were excluded because the studies were performed on elderly patients, or subjects with various neurologic or debilitating co-morbidities. Therefore, a number of articles that examined functional performance tests did not fit the inclusion criteria. It is possible some of these functional performance tests may have value in a population of subjects with musculoskeletal dysfunction. Given the volume of articles reviewed, it is also possible some functional performance tests were not identified. Significant variations in the descriptions of functional performance tests used by different authors were common. This may alter interpretation of the values attained for a specific functional performance test.

In conclusion, only the deep squat and single-leg stance test demonstrated evidence of validity in a population of patients with hip-related dysfunction. Specifically, diminished squat depth and provocation of pain during the single-leg balance test may be an indication for FAI and gluteal tendinopathy, respectively. The SEBT and single-leg squat test provided evidence of validity through an analysis of kinematics and muscle function in healthy subjects. There were 20 functional performance tests, including the FMS™, with evidence of reliability and normative data to help in score interpretation. None of the articles provided evidence of reliability in a group of subjects with hip-related dysfunction. Without established reliability for these functional performance tests it limits the ability of the clinician to confidently interpret test results and utilize the tests to measure patient progress. The results of the systematic review demonstrated few functional performance tests that have established validity and reliability to compliment traditional clinical exam procedures for patients with hip dysfunction. Further study is needed to establish the reliability and validity of existing functional performance tests or explore new, relevant functional performance tests to be used in a young, athletic population with hip dysfunction.

**REFERENCES**


ABSTRACT

Background and Purpose: Distal biceps brachii tendinosis is a relatively uncommon clinical diagnosis seen by physical therapists. As a result, there is little evidence guiding clinical decisions regarding best practice or effective treatment options to restore individuals to their previous level of function. The purpose of this case report is to describe the use of eccentric training as the primary intervention in the rehabilitation of a patient with distal biceps tendinosis.

Case Description: A 41-year-old male electrician and collegiate wrestling coach presented to a university outpatient physical therapy clinic with a two month duration of pain in the right antecubital space which occurred when the patient was performing close-grip body weight curl ups for the first time. Sharp pain was noted in the right arm during the lowering phase of the exercise. Following the examination, distal biceps tendinosis appeared to be the likely diagnosis. The patient was educated in eccentric exercise principles and was prescribed eccentric loading exercises for the distal biceps brachii tendon in two different positions of elbow flexion.

Outcomes: The patient was seen in physical therapy for three visits over the course of four weeks. Following eccentric training, the patient reported decreased pain, demonstrated increased right elbow flexion and forearm supination strength, was no longer tender to palpation of the distal biceps tendon and showed clinically significant improvement in QuickDASH scores.

Discussion: Given the lack of available research on the rehabilitation of distal biceps tendinosis, eccentric training showing benefits with other upper quarter tendinoses and the positive outcomes in this case, it may be appropriate for physical therapists to employ eccentric training for patients with distal biceps tendinosis.

Key Words: distal biceps, eccentric exercise, tendinosis

Level of Evidence: 5 (Single case report)
INTRODUCTION
Distal biceps brachii tendinosis is a relatively uncommon clinical diagnosis seen by physical therapists. As a result, there is little evidence guiding clinical decisions regarding best practice or effective treatment options to restore individuals to their previous level of function. Eccentric training is well documented as an effective method of rehabilitating both achilles and patellar tendinopathies as well as more recently, tendinopathies of the upper quarter specifically the rotator cuff and wrist extensor mechanism. Eccentric training of patients afflicted with these tendinopathies can result in positive changes in pain, function, and tendon characteristics. Given these outcomes it seems reasonable to consider eccentric training as a potential intervention for the diagnosis of distal biceps tendinosis. The purpose of this case report is to describe the use of eccentric training as the primary intervention in the rehabilitation of distal biceps tendinosis.

Most authors have encouraged use of the term of tendinopathy versus tendinitis in describing overuse tendon injuries in athletes. These recommendations in specific vocabulary are secondary to evolving evidence of histopathological classification defined by tendon degeneration without signs of inflammation. Understanding the differences in tendon pathology can allow clinicians to better treat these conditions.

Tendinosis is tendon degeneration resulting from a failed healing response without clinical or histological signs of inflammation. Microscopic evaluation of tendinosis reveals collagen disorientation, disorganization and fiber separation by an increase of mucoid ground substance, increased prominence cells and vascular spaces with or without vascularization and focal necrosis or calcification. It is not clear whether the initial event in the pathologic cascade occurs in the collagen matrix or the tenocyte. Injury to the tendon may result in collagen fiber disruption that may either trigger mechanoreceptors or directly damage the tenocytes causing them to replicate and differentiate into fibrocytes, endothelial cells, and other mesenchymal-derived cells. These cells then produce the hypercellularity, hypervascularity, collagen disorganization, and abnormal ground substance deposition seen in tendinosis lesions. Another characteristic specific to tendinosis is neovascularization, or the proliferation of capillaries and arterioles. This inappropriate tissue orientation leads to delayed healing which prolongs the duration an individual experiences symptoms, most frequently reported as pain, however the tendon may also be asymptomatic. Tissue biopsy or microscopy is typically required in order to define tendon dysfunction specifically as tendinosis. For the purposes of this case report, the phrase tendinosis represents a chronic tendinopathy, without confirming biopsy or microscopy having been performed.

Tendonitis is defined as an active inflammatory process within the substance of the tendon. The inflammatory process includes hemorrhage and organizing granulation tissue with fibroblastic proliferation. The tendon is symptomatic with vascular disruption and an inflammatory reparative process. The duration of the inflammatory process can depend on a number of factors, but in most cases it lasts up to three weeks.

Paratenonitis is defined as inflammation of the paratenon or outer layer of the tendon; typically occurring where a tendon frictions over a bony protuberance. Typically paratenonitis presents with acute swelling and hyperemia progressing to inflammatory cells and fibrinous exudate within the tendon sheath with palpable crepitus.

Incidence
To date the incidence of distal biceps tendinosis has not been well reported, with available literature discussing either partial or complete tendon ruptures. Specifically, the successful rehabilitation of an individual with distal biceps tendinosis has yet to be described in detail in current literature. Safran and Graham reported an incidence of distal biceps ruptures as 1.2 per 100,000 patients with the majority of injuries (86%) affecting the dominant arm. Sutton and colleagues reported 90% of biceps brachii tendon ruptures occur at the proximal origin of the tissue while only 10% of biceps tendon ruptures are distal indicating a low frequency of distal bicep brachii injuries, with actual tendinosis being reported even less frequently. Males in the 4th decade of life are more likely to undergo distal biceps tendon injuries, with injuries typically occurring between the ages of 30 and 60 years of age. In addition to age, smokers have a 7.5 times increased risk of injury than non-smokers.
Mechanism of Injury
The distal biceps tendon is most commonly injured when an eccentric force is applied to the flexed elbow, with patients typically complaining of a sudden, sharp, and painful tearing sensation in the antecubital region. There are two main theories explaining possible predisposition of the distal aspect of the biceps to injury. The first deals with the vascular supply of the distal biceps. Proximally, the biceps brachii receives branches of the brachial artery, but the distal vascular supply comes from the smaller posterior interosseous artery. There is an approximate 2.14 cm zone of avascularity that can predispose the distal biceps tendon to injury. The second theorized predisposition for distal tendon degeneration involves mechanical impingement of the biceps tendon at the proximal radioulnar joint. With the forearm in a fully pronated position, the distance between the lateral border of the ulna and the radial tuberosity is 48% less than the distance with the forearm fully supinated, thus decreasing the available space for the tendon. Also, with the forearm pronated, the biceps tendon occupied on average 85% of the radioulnar space at the level of the tuberosity. While these theories have not been determined to be definite causes of biceps tendon pathology, they are the most widely reported in literature to date.

Anatomy
In order to effectively treat distal biceps dysfunction, clinicians must understand the anatomy. The biceps brachii consists of two heads: the short head which originates at the coracoid process and the long head which originates at the supraglenoid tubercle before blending in with the superior aspect of the glenoid labrum and running along the intertubercular groove. Muscular actions include elbow flexion and forearm supination as well as assisting in glenohumeral flexion, glenohumeral abduction (if the humerus is externally rotated) and stabilizing and depressing the humeral head.

Ten of 17 subjects demonstrated two distinct parts of the distal biceps tendon insertion, each a continuation of the long and short heads of the biceps, with the remaining 7 subjects demonstrating interdigitation of the muscle. The short head of the biceps typically inserts into the distal aspect of the radial tuberosity allowing it to be a more powerful elbow flexor, while the long head attaches more proximally on the radial tuberosity in a position to supinate the forearm. The bicipital aponeurosis (lacertus fibrosis) consists of three layers and completely encircles the ulnar forearm muscles, acting to stabilize the biceps tendons distally as well as the ulnar forearm musculature proximally. Biceps brachii innervation comes from the musculocutaneous nerve, cervical roots C5 (primarily) and C6.

Case Description: Patient History and Systems Review
A 41-year-old male presented to physical therapy with severe localized pain in the right antecubital fossa which had been worsening in the previous two months. The onset of pain occurred when the patient was performing close-grip body weight curl ups for the first time, during which he experienced sharp pain during the lowering phase of the 10th repetition of the third set. In this case, close-grip curls ups were performed with hands approximately six inches apart and forearms supinated. Exacerbating activities included lifting heavy weights, wrestling motions involving extreme shoulder internal rotation and/or elbow flexion and he also noted some mild increased pain if he had to turn his palm up frequently at work into forearm supination. The patient was able to continue working full time as an electrician (which required frequent overhead activities) and coaching collegiate wrestling. No specific alleviating factors aside from rest were noted. No complaints of proximal pain were reported. No other significant past medical history or history of orthopedic injuries was reported. The patient was not taking any medications. No previous treatment had been reported aside from three days of complete rest with some benefit following the initial injury. The patient had no history of smoking and did not drink alcoholic beverages while in training. Previous diagnostic imaging included an x-ray which was normal. The patient was right hand dominant. The patient's activity level at time of evaluation included lifting weights and wrestling five times each week. Prior to the injury, the patient reported lifting weights and wrestling with about the same frequency since being a teenager, however intensity of both weight lifting and wrestling decreased following the injury secondary to pain. The patient had performed body weight pull ups and curl ups...
prior to the injury; however he did not perform close-grip curls ups prior to when the injury occurred.

The patient was scheduled to participate in a Veteran’s level Greco-Roman wrestling tournament in Russia two months after the date of initial evaluation and wanted to alleviate symptoms as quickly as possible. The patient wanted to try physical therapy rather than undergo a platelet-rich plasma injection, an option presented to him by his orthopedic physician, because of his concern that injections might exacerbate his symptoms.

**Clinical Impression #1:**
After reviewing the medical intake form and obtaining a thorough history, distal biceps tendinosis was the initial clinical hypothesis. The patient reported a mechanism of injury consistent with biceps brachii pathology, noted localized pain at the distal aspect of the biceps brachii and had pain with elbow flexion and forearm supination, two actions of the biceps brachii. Based on the chronicity of the patient’s symptoms, a tendinosis seemed more likely than a tendinitis. A partial tear and a tendinosis may present similarly, making differentiation with a clinical exam difficult. Diagnostic imaging, particularly ultrasound or magnetic resonance imaging (MRI) can be helpful to differentiate the two diagnoses.

Complete tendon rupture was not expected because the patient was able to continue with all activities, but performed them with pain. Cervical pathology seemed less likely because the patient did not report any symptoms with neck movement or positioning, and symptoms did not follow a particular cervical referral pattern.

By performing a thorough examination to confirm a tendinosis it would make eccentric training more appropriate, as a tendinitis typically heals from modified and limited activity rather than overloading inflamed tissues. Prior to examination the patient appeared appropriate for eccentric training given his reported symptoms consistent with a tendinosis, his high level of understanding of weight training principals and willingness to try conservative measures.

**EXAMINATION**
A thorough examination was performed of the patient in order to determine the specific tissues involved in causing the patient’s symptoms:

**Posture:** In sitting, the patient presented with a forward head and protracted scapulae posture. In standing there was a noticeable improvement of posture as a visual and palpatory inspection revealed no significant findings or asymmetries in scapular boney landmarks (acromion and inferior angle position). Scapulohumeral rhythm during bilateral shoulder elevation was normal. Patient was 6’0” tall, 242 pounds with a mesomorphic musculoskeletal appearance.

**Cardiopulmonary Screen:** Blood pressure: 118/70 mmHg; resting heart rate: 58 bpm, 2+ (normal) pulse noted at both brachial and radial pulse sites; respiratory rate: 12 bpm; all within normal limits

**Cervical Screen:** Negative for reproduction of symptoms or discomfort

**Range of Motion (ROM):** Upper extremity active ROM was within functional limits and pain free throughout. Active and passive ROM at the elbow was pain free.

**Sensation:** Intact to light touch throughout bilateral neck/upper extremities in all dermatomal distributions.

**Palpation:** Localized tenderness was noted at the right distal biceps tendon insertion at the radial tuberosity and running proximally for 2 cm over the biceps tendon in the antecubital fossa. Palpation of the medial and lateral epicondyles, the common wrist flexor and extensor tendons, brachioradialis, brachialis, supinator, median, ulnar and radial nerves did not reproduce pain. No retraction or defect consistent with a complete rupture was noted. No warmth or swelling was present when compared bilaterally. The biceps muscle belly and proximal biceps tendon were not tender to palpation.

**Myotomes:** Grossly 5/5 bilaterally in the neck/upper extremities except the right elbow flexors which were 4/5 and demonstrated pain upon resistance testing.

**Manual muscle testing (MMT):** Right elbow flexion with forearm supinated (to bias biceps brachii): 4/5 with reproduction of pain at the distal biceps tendon; elbow flexion with the forearm in neutral (‘hammer curl’ position to bias brachioradialis): 4/5 with reproduction of pain at the distal biceps tendon; elbow
Involvement it appeared that the right distal biceps brachii tendon was the tissue involved.

‘Special’ Tests: Yergason’s, Speed’s, Hook, and Bicep Squeeze tests all yielded negative results. The procedures, indications and available statistical information of these tests can be seen in Appendix 1.35-37

Reflexes: Biceps, brachioradialis and triceps were normal (2+) and symmetrical bilaterally

Neural Tension: Upper limb tension test (ULTT) median nerve bias was negative bilaterally

Diagnostic Ultrasound: Hypoechoic signal was noted throughout the length of the distal tendon and location of pain. Substantial enlargement of the right distal biceps tendon was not noted when compared to the left.

Pain Score (verbal analog scale: 0-10, 0 being no pain, 10 being worst pain ever experienced): Current: 5/10; Least since onset: 5/10; With activity: 10/10; Worst since onset: 10/10.

QuickDASH (Three sections each scored 0-100, 0 is no disability): Main module: 27.3; work module: 0; sports/performing arts module: 87.5

Clinical Impression #2
Given the fact that the patient’s symptoms were brought on by particular motions involving the biceps brachii coupled with the patient’s report of a traumatic onset, non-mechanical sources of pain causing symptoms were ruled less likely. The patient’s cardiovascular screen was normal and no complaints of ischemic type pain were reported, indicating vascular compromise of the area was also unlikely. A cervical screen was negative as was a neural screen (ULTT, reflexes and light touch sensation) ruling out a radicular or nerve entrapment source of symptoms. Given the anatomy and function of the biceps brachii, injury to the distal aspect is generally accompanied by pain and/or weakness with resisted elbow flexion and/or supination both of which were noted with this patient. Proximal biceps brachii involvement was ruled out by the absence of symptoms, and negative Speed’s and Yergason’s tests. Given the point tenderness along the distal biceps tendon, mechanism of injury, and ruling out of proximal bicep involvement it appeared that the right distal biceps brachii tendon was the tissue involved.

With a tendinitis, physical markers of inflammation such as edema, redness or warmth may be expected. These signs were not present with this patient. Also, this patient had been experiencing symptoms for two months prior to coming to therapy, long after a tendinitis would be expected to last. Additionally, the patient was able to continue all daily and vocational activities using the right biceps brachii (duties required of an electrician, carrying his children, etc) without being limited by pain, and participate in wrestling and weight lifting with pain. If a tendinitis was the pathology, symptoms would likely limit all activities stressing the involved tissues, not necessarily just activities with heavy weights or large resistance. Diagnostic ultrasound imaging can also be an effective method of determining the appropriate pathology. A tendinosis typically appears as hypoechoic swelling of the tendon on diagnostic ultrasound, as compared to hypoechoic tendon fiber disruption seen frequently with a tendon tear.38 Partial tears are usually characterized by enlargement and abnormal contour of the tendon, with peritendinous fluid (edema, bursitis, hemorrhage) occasionally seen.39 Although substantial enlargement was not noted at the right distal biceps tendon, hypoechoic swelling consistent with tendinosis was visualized.

Plain radiographs sometimes show hypertrophic bone formation at the radial tuberosity with partial tears27 however, radiographs of the elbow of this patient did not show significant abnormalities. With a complete rupture, the proximal position of the biceps muscle belly is often visually readily apparent.31 This was not the case with this patient, making a complete rupture less likely. Based on the results of the examination, the initial hypothesis of distal biceps tendon, hypoechoic swelling consistent with tendinosis was visualized.

Informal re-evaluation was performed at each follow up visit. Formal reassessment of tests and measures performed during the initial evaluation was performed four weeks after initial evaluation (one month prior to the competition). Objective measures comparing initial evaluation and the patient’s status at discharge can be seen in Table 1. Outcome measures were pain, strength, tenderness to palpation and QuickDASH scores. The QuickDASH is an abbreviated version of
the validated Disabilities of the Arm, Shoulder and Hand (DASH) outcome measure, investigating a patient's reported level of disability in upper extremity function. With this outcome measure, lower scores are indicative of less disability while higher scores indicate greater reported disability. The minimum clinically important difference (MCID) has been determined to be 8 points.40

**INTERVENTION**

Eccentric contractions occur as the muscle is lengthening under an external load. During eccentric training, the involved limb is used to control the lowering phase (muscle lengthening), while the uninvolved limb performs the concentric phase in order to return the weight to the starting position. The patient is told to perform this exercise even if they experience pain (as muscle contractions of damaged tendons can be painful), however the patient is told to stop exercising if the pain becomes disabling. Weight is increased when the patient can perform the eccentric loading without experiencing any minor pain or discomfort.1

Visit 1 (initial evaluation): Given the likely clinical diagnosis of distal biceps tendinosis, the patient was educated and trained with eccentric loading for elbow flexion with the forearm supinated (Figure 1) and with the forearm in neutral (Figure 2). The patient was instructed to use a weight that was uncomfortable or slightly painful, but not disabling (this weight was determined to be 30#, as the patient felt 25# was too easy, however 35# was too painful and the patient was unable to maintain proper form). The patient demonstrated appropriate performance using a cable column in the physical therapy gym. Training was to be performed every day, at 3 sets of 7 repetitions, increasing weight in increments of 5 pounds if 7 repetitions were reported as easy or pain-free. There is some inconsistency in exercise prescription for eccentric loading.11 The patient was prescribed fewer repetitions than Alfredson's achilles protocol1 (3 sets of 15 repetitions, 2 times each day) because the patient was performing the activity in two different positions (increasing total number of eccentric loading repetitions). Also it was the author's hypothesis that fewer repetitions would be needed to overload the distal biceps tendon than the Achilles or patellar tendons which are involved in repetitive weight-bearing activities such as gait (where resistance under normal loads is greater than in the upper extremity). Significant time was spent with patient education regarding the eccentric training process and its physiology. In addition, patient education was provided regarding proper posture (specifically trying to maintain spinal neutral and avoiding protracted scapular positioning) and the idea of proximal stability in order to facilitate proper mobility distally.41,42 The patient was scheduled for a follow up in two weeks, and was instructed to contact the physical therapist should any questions arise or if symptoms were to worsen.

<table>
<thead>
<tr>
<th>Table 1. Outcome measurements at initial evaluation and discharge.</th>
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<tbody>
<tr>
<td><strong>Pain</strong></td>
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<tr>
<td>---</td>
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<tr>
<td>At rest</td>
</tr>
<tr>
<td>At worst</td>
</tr>
<tr>
<td><strong>QuickDASH</strong></td>
</tr>
<tr>
<td>Main module</td>
</tr>
<tr>
<td>Work module</td>
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<tr>
<td>Sports module</td>
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<tr>
<td><strong>Strength</strong></td>
</tr>
<tr>
<td>1) forearm in neutral</td>
</tr>
<tr>
<td>2) forearm pronated</td>
</tr>
<tr>
<td>3) forearm supinated</td>
</tr>
<tr>
<td>Forearm supination</td>
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</tbody>
</table>

**Tenderness**

Distal biceps tendon

(+) on right
(-) on right
Visit 2 (2 weeks after initial evaluation): The patient reported compliance with eccentric training over the previous two weeks. Subjectively, the patient reported pain was decreasing at rest and with exacerbating activities but remained (1/10 at rest, 5/10 at worst). Objectively, no significant improvements were noted with muscle strength testing; however less pain was reported with all motions. Tenderness remained at the distal biceps tendon, but again was reported with decreased intensity. After proper form without compensation was demonstrated to the physical therapist with increased weight (40#) in both positions, the
patient was instructed to continue with eccentric training increasing weight as needed to continue to overload the involved tissues and remain in an uncomfortable/painful range. Sitting posture improved, as the patient was able to sit with decreased forward head/rounded shoulder positioning without cues. The patient also reported noticing himself sitting and standing in a neutral scapular position more frequently at home and at work. Resisted wrist flexion and extension was introduced to increase neuromuscular control at the elbow (5#, 3 sets of 10 repetitions each exercise, 5 times each week). The patient was also given a gentle self-stretch for the elbow flexors, which involved passively extending the wrist of the involved arm with the contralateral hand all while the involved elbow remained in extension. This stretch was to be held for 30 seconds each repetition, performing 2-3 repetitions, 2-3 times a day. Performance of the new activities was correct without compensation or increased pain. The patient was scheduled for another follow up visit in two weeks.

Visit 3 (4 weeks after initial evaluation): The patient reported continued compliance with the HEP. The patient reported no pain with previously exacerbating factors and demonstrated no pain with resistive testing of elbow flexion (three positions) or with palpation. Eccentric exercises were performed with correct technique with increased weight (55#) using a cable column. With continued improvement in symptoms, new activities were incorporated to force co-contraction of the upper quarter and trunk, which commonly occurs during wrestling. When training the upper quarter for wrestling, activities should emphasize both single and double-extremity movements focusing on stability and proprioception. Activities were normal (Figure 3) and close grip (Figure 4) pushups on a BOSU® ball (Hedstrom Fitness, Ashland, OH) with feet on a theraball, a challenging exercise forcing co-contraction during a dynamic activity on an unstable surface. Also added was a serratus anterior exercise with the cable column. While kneeling on a BOSU® ball and starting with resistance in the upper extremity, the patient slowly allows the weight to return towards the cable column making sure to control scapular protraction (Figure 5). The patient performed the new exercises with proper form and no pain. The patient was educated to incorporate the new exercises into his current exercise program, performing 3 sets of 10 repetitions for each exercise, 5 times a week.

OUTCOME
The patient was seen in physical therapy for three visits including the initial evaluation over the course of four weeks. At the third visit, the patient was pain free with all work, sport and recreational activities and had been for the previous week. The Quick-DASH was reassessed at the third visit with scores of 0% in the main, work, and sports modules, indicating no reported upper extremity dysfunction. The patient was happy with the progress made as he was able to return to pre-injury status and had decided...
The patient was discharged as a result of accomplishing all goals, being independent with his HEP and being pain free. The patient had the physical therapist's contact information should questions arise regarding his care or should his symptoms change. An e-mail received two weeks following the third visit (6 weeks after initial evaluation) revealed that the patient remained pain free despite an increase in training intensity. In a follow up e-mail six months after initial evaluation checking for long term improvement, the patient mentioned that he was able to participate in the wrestling tournament without pain, finishing third in his weight class. The patient also mentioned that he was not experiencing any pain in his arm, and was not limited functionally with any recreational or vocational activities.

**DISCUSSION AND CONCLUSIONS**

To date there has been little literature describing distal biceps tendinosis or its rehabilitation. By definition, a tendinosis is an abnormal collection of disorganized collagen fibers, which can delay proper healing following injury. Mechanical loading of tissues is believed to accelerate tenocyte metabolism and may speed repair. Eccentric training has been shown to be beneficial for the treatment of tendinosis by normalizing tendon structure.

Numerous studies have demonstrated positive outcomes with eccentric training for upper quarter tendinopathies, particularly the rotator cuff and wrist extensor mechanism. Because eccentric training has not been shown to have detrimental effects and in light of the positive outcomes of other upper quarter tendinoses, it may be appropriate for physical therapists to attempt eccentric training for patients with distal biceps tendinosis as similar tissue healing principles apply.

There are a number of limitations associated with this case report. In this particular case, the patient was instructed to perform 3 sets of 7 repetitions of eccentric elbow flexion with the forearm in neutral and in supination each day, less than Alfredson's established protocol of 3 sets of 15 repetitions two times each day for Achilles tendinosis. This recommendation has not been validated for the distal biceps tendon in previous research, but was still effective. This may be because the patient's high level of function at onset of therapy and his performance of additional eccentric loading of the biceps tendon against resistance while wrestling. It was the physical therapist's hypothesis that the Achilles tendon is active with gait, a repetitive activity performed throughout the day with full body weight, and may require more repetitions of eccentric contractions to overload. Because the biceps brachii is typically used less frequently to produce less force, the physical therapist felt fewer repetitions would be needed to overload the tendon, addressing abnormal collagen cross-links and facilitating proper healing and pain free function. Also, many of the studies previously performed on the effect of an eccentric training protocol on tendinopathies implemented
a 12 week program duration, longer than this particular patient performed eccentric training, making a direct correlation between this case and supportive research difficult. Despite the longer duration of training with previous studies, there have been positive outcomes shown within four weeks of eccentric training for tendinosis. Logistically, this patient was a wrestling coach at a university who had free access to weights to perform eccentric activities, which may have aided his recovery. Some patients may not have access to gyms, so household items (i.e. a weighted bag or backpack) may need to be utilized to overload tissues in accordance to eccentric loading principles. This is also the first article describing a rehabilitation program of a distal biceps tendinosis using eccentric training. Additional research is needed to determine the clinical utility of eccentric training in this patient population.

It should also be made clear that although this patient presented with an isolated distal biceps tendinosis, a complete evaluation of every patient should be performed. Every attempt should be made to assess and correct impairments in posture, strength, ROM and neuromuscular control that may increase the physical demand on the biceps during daily, vocational, or recreational activities. It is the authors’ hope that this case report will increase awareness of distal biceps tendinosis and facilitate continued investigation into the most effective conservative treatment interventions in order to effectively and efficiently maximize a patient’s pain free level of function.

REFERENCES


### Appendix 1. Biceps brachii special tests.

<table>
<thead>
<tr>
<th>Test</th>
<th>Procedure</th>
<th>Interpretation</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Likelihood Ratio (LR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yergason’s</td>
<td>With the patient’s elbow flexed to 90°, stabilized against the thorax, and forearm pronated, the examiner manually resisted supination while the patient also externally rotated the arm against resistance.</td>
<td>A positive result was pain over the bicipital groove and/or subluxation of the long head of the biceps brachii, indicating proximal biceps tendonitis or instability.</td>
<td>0.41</td>
<td>0.79</td>
<td>+LR: 1.94 –LR: 0.74</td>
</tr>
<tr>
<td>Speed’s</td>
<td>With the patient’s arm elevated to 90° of forward flexion, the elbow extended, and the forearm supinated. The examiner applied resistance distal to the elbow in the direction of arm extension</td>
<td>A positive test is indicated by localized pain over the bicipital groove, indicating proximal biceps tendon dysfunction; may also be indicative of a SLAP lesion.</td>
<td>0.54</td>
<td>0.81</td>
<td>+LR: 2.77 –LR: 0.58</td>
</tr>
<tr>
<td>Hook</td>
<td>While the patient actively supinates with the elbow flexed 90 degrees, an intact hook test permits the examiner to hook his or her index finger under the intact biceps tendon from the lateral side</td>
<td>A positive result is where there is no cord-like structure under which the examiner may hook a finger, indicating distal biceps tendon avulsion.</td>
<td>1.00</td>
<td>1.00</td>
<td>+LR: ∞ –LR: ∞ (based on one study)</td>
</tr>
<tr>
<td>Squeeze</td>
<td>Similar to the Thompson test for an Achilles tendon rupture, the biceps muscle belly is squeezed in order to elicit a contraction.</td>
<td>If no forearm supination is elicited with squeezing the muscle belly a complete rupture may be indicated.</td>
<td>0.96</td>
<td>Not Reported</td>
<td>Not Reported</td>
</tr>
</tbody>
</table>
ABSTRACT

Clients presenting with ulnar-sided wrist pain can provide diagnostic and management challenges for physical therapists. Symptoms in this region may originate from multiple structures. Integration of clinical examination and diagnostic imaging results is often required for optimal decision-making and patient management. To obtain the most informative imaging results, practitioners need an understanding of injury patterns and their detection by various imaging modalities. This case describes a mature golfer who presented with persistent ulnar-sided wrist pain and was eventually determined to have a fracture of the hook of the hamate accompanied by neighboring soft tissue involvement also contributing to his symptom complex. His history and the diagnostic process are detailed along with a brief discussion of his subsequent management post-operatively.

Level of Evidence: 5 (Single Case Report)

Key Words: wrist pain, hamate fracture, golf injury
The hook or hamulus of the hamate arises palmarly as a curved process from the body of the bone and serves as a pulley for the fourth and fifth flexor tendons. The hook also provides a point of attachment for the flexor retinaculum at its peak. Other attachments include the flexor carpi ulnaris, flexor digiti minimi, and opponens digiti minimi. By virtue of these attachments, the hook of the hamate contributes to the borders of the carpal tunnel and tunnel of Guyon. The latter tunnel provides for passage of the ulnar artery and nerve to pass distally into the palmar aspect of the hand.

From an embryological perspective, the body and the hook of the hamate develop separately before fusing at approximately 15 years of age. Occasionally, this fusion may not occur, resulting in an ossicle located volarly to the body of the bone. The presence of such an accessory ossicle can sometimes complicate interpretation of imaging, mimicking a fracture.

Fractures of the hook of the hamate are considered to be relatively rare. The reported frequency with which they occur, however, lacks current data. Some investigators suspect fractures of the hook of the hamate are increasing in frequency because of growing popularity of sports such as golf, baseball, tennis, and other racquet sports, increasingly played year-round. The onset of symptoms in many individuals may be a stress related sequence of events because of the repetitive grasping and loading of the hypothenar eminence with sports requiring an implement. In sports in which a racquet is held, the dominant hand is usually affected. In sports in which both hands grasp an object, the leading or non-dominant hand is most frequently affected. In addition to sports with a piece of equipment being grasped, hook of the hamate fractures have also been reported with rock climbing due to the repetitive grasping required in this activity. The mechanism of injury can also be macrotraumatic, such as falling on an outstretched hand or other direct trauma. Fractures of the hamate are generally classified as being Type I, involving the hook of the bone, and Type II, with the fracture line being in the body. Some authors further distinguish fractures based on the orientation of the fracture line within the body.

Correct diagnosis and management of ulnar-sided wrist pain can present a dilemma for the physical therapist. Among the causes of pain to be considered during the process of differential diagnosis are ulnar nerve injury, intercarpal instability, extensor carpi ulnaris tendon subluxation, tenosynovitis, triangular fibrocartilage complex injury, ulnar impaction syndrome, ulnar artery thrombosis, Kienböck’s disease, or potentially fractures of the regional osseous structures such as the ulnar styloid process, triquetrum, or hamate. Hook of the hamate fractures may be particularly difficult to identify because of the base of the hook of the hamate not being well visualized with the usual radiographic views and a lack of distinguishing findings on clinical examination. Understanding and integrating the patient's history, clinical examination findings, and diagnostic imaging indications and results are important for optimal decision making and patient management. In this case report, each of these aspects of the individual patient were informative in arriving at a correct diagnosis and guiding the course of care.

CLINICAL PRESENTATION

A 66 year-old retired male reported a 10 to 12 week history of left ulnar aspect wrist pain without recollection of a specific event initiating the pain. He noted the symptoms being present only intermittently during golf, specifically upon striking the golf ball. He was unaware of any symptoms during his daily activities otherwise. With rest and non-use of the involved hand, his symptoms would completely subside. With golf, however, the symptoms would occasionally reach 8 of a possible 10 on a verbal analog numerical pain scale (0 = no pain, 10 = extreme pain). In an attempt to manage his pain, he taped his wrist or used another form of an external support wrap.

On a particular occasion of playing golf in cooler weather, he struck the golf ball for a drive, experiencing a sudden, marked increase of pain. This exacerbation did not quickly subside and he was subsequently unable to continue playing. He began use of an over-the-counter wrist splint and sought care within the military medical system with which he was associated.

Initial radiographs were ordered by a certified hand therapist (CHT) as the primary contact clinician. These radiographs, in posterior-anterior and lateral views, were interpreted as negative for fractures by a radiologist within the same medical system (Figures 1 and 2). At this time, mild edema was evident in the hypothenar region and along the ulnar aspect
of his wrist. Pain was reproduced with active ulnar deviation and passively in the same motion with overpressure, and also with active radial deviation, and with resisted wrist extension combined with ulnar deviation. Active wrist flexion and extension and the same passive motions with and without overpressure were of normal range and pain-free.

Palpation revealed mild to moderate diffuse tenderness and pain on the palmar and ulnar areas of the left wrist. This included along the ulnar collateral ligament, extensor carpi ulnaris, the hook of the hamate, and dorsally at the distal end of the ulna. Additionally, tenderness was noted in hypothenar region of the left palm, but localization was difficult because of acuity and the diffuse nature of the pain. Light touch sensation and two-point discrimination were noted to be intact and comparable to the unaffected hand. Grip strength was decreased as measured at 80 pounds on the affected left side and 160 pounds on the dominant right (Jamar® Hydraulic Hand Dynamometer # J00105, Lafayette Instrument Co., Lafayette IN).

Additional Imaging
Upon the patient’s consultation with an orthopedic surgeon, the decision was made to obtain magnetic resonance imaging (MRI) of the wrist for suspicion of injury to the triangular fibrocartilage complex. The MRI revealed, however, a nondisplaced fracture of unknown duration near the base of the hook of the hamate (Figure 3). On the T2-weighted MRI sequences, changes in signal intensity were also present surrounding the tendon of the extensor carpi ulnaris, suggesting inflammation of this structure. Also present was intermediate signal intensity degeneration of the scapholunate ligament and lunotriquetral ligaments without specific evidence of a tear or interval widening. These finding are consistent with degenerative change, but findings suggestive of instability were not present. The initially suspected origin of symptoms, the triangular fibrocartilage complex (TFCC), demonstrated degeneration, particularly at the ulnar attachments without evidence of a focal tear. Note the heterogenous signal intensity within
the TFCC and the fenestration of its attachments as demonstrated in Figure 4. There was also mild reactive marrow edema of the adjacent ulnar styloid.

**Initial Management**

Given the unknown age and nondisplacement of the hamate fracture accompanied by multiple soft tissue findings, a trial of conservative care was initially chosen. A six day course of methylprednisolone was prescribed to address inflammation and a custom-made splint was fabricated to limit wrist motion while allowing metacarpophalangeal motion. These interventions resulted in reduction of symptoms to a focus in the ulnar aspect of the wrist. At this time, further examination using the Pull Test resulted in provocation of pain at that specific focal area. The Pull Test as a specific clinical exam procedure has been proposed to screen for hook of the hamate fractures.1 For this exam procedure, the patient’s wrist is placed in full ulnar deviation with the digits of the involved hand flexed. The examiner then pulls distally on the fourth and fifth digits with the patient attempting to resist the examiner’s pull (Figure 5). If positive, the test will result in pain provocation in the patient’s wrist and palmar area. The focal area of pain is likely to be the hook of the hamate. The test has only been reported for its accuracy in a case series of five patients with exam results in all five matching computed tomography (CT) imaging.1 Psychometric values have yet to be established to determine its overall clinical utility. Additionally, palpation now similarly revealed isolated pain over the hook of the hamate as the surrounding tenderness had subsided. These clinical findings combined with the MRI results were viewed as confirmatory regarding the hook of the hamate fracture being the symptom origin.

One week later, the hook of the hamate was excised. Excision of the fractured hook of the hamate is the typical course of care for fractures at the base of the hook, and has been found to provide reasonably
good long-term results with few complications.\textsuperscript{6,7,9} Immediate post-operative care consisted of dressing for the wound and a protective splint.

**EVALUATION AND IMAGING**

The interview with the patient with a hook of the hamate fracture will usually be informative with regard to a history of onset of pain when swinging an implement such as a bat, golf club, or racquet.\textsuperscript{1} Rock climbing, as previously noted, has also been implicated as an activity precipitating similar symptoms.\textsuperscript{10}

Palpation of the hook of the hamate is often most easily done by locating the pisiform and then moving one finger width distally and one finger width radially. Tenderness upon direct palpation of this structure is one of several findings that would raise suspicion of a possible fracture. Other findings could include palmar pain increased by grasping, pain with combined wrist extension and ulnar deviation, pain with flexion of the fourth and fifth digits (particularly when resisted), decreased grip strength, and paraesthesia of the fourth and fifth digits.\textsuperscript{2,5,7} Injury of the flexor tendons may also occur and may actually be the precipitating symptoms causing care to be sought.\textsuperscript{5} Accurate diagnosis often delayed with stress fractures because of the absence of trauma, despite persistent pain.\textsuperscript{1,4,12,13}

Particular clinical suspicion for the possibility of a hook of the hamate fracture may be appropriate when pain in the region persists with a history and exam findings as described above along with no diagnostic imaging or limited radiographic views. Unless a fracture of the hook of the hamate is specifically considered, the applicable radiographic views or more sensitive diagnostic imaging may not be completed. Posterior-anterior (PA) and lateral view radiographs of the wrist often do not reveal a discrete fracture line within the hamate.\textsuperscript{2,5,9,14} Thus, the interpretation of radiographs from conventional PA and lateral views as negative for fracture does not necessarily rule out the possibility of a fracture at the base of the hook. Carpal tunnel view radiographs have been advocated,\textsuperscript{15} but full wrist extension is required for the base of the hook to be visualized and may not be available because of pain. Additionally, identification of fractures has been reported using oblique view or modified semisupinated oblique view radiographs, if such positioning is tolerated.\textsuperscript{2,4,5} These views are described in the American College of Radiology (ACR) Appropriateness Criteria, which states that when fractures of the hook of the hamate are suspected, semi-supinated and carpal tunnel projections are indicated in addition to standard PA and lateral views of the wrist. Within the ACR Appropriateness Criteria, various forms of clinical presentations are described to provide evidence supported corresponding best imaging methodology. This taxonomy provides for levels of recommendations of indicated imaging modalities and their applications. Under Variant 8 of Hand and Wrist Trauma within the ACR Appropriateness Criteria, CT is recommended, if radiographs are equivocal in the presence of strong clinical suspicion. The additional radiographic special views and CT are each recommended at the highest level of 9, as being the most indicated.\textsuperscript{16} The multiplanar capabilities of CT provide for a greater level of accuracy in fracture detection. Radiography employing the special views has been described as having 80.5\% to 90\% accuracy in detecting hook of the hamate fractures, whereas CT has been noted to be 97.2\% to 100\% accurate.\textsuperscript{17,18} The axial CT views are often most revealing of the fracture.\textsuperscript{5,18} Additionally, CT can provide information as to the severity of displacement, if present, which may be valuable in decision making.\textsuperscript{14} In non-displaced fractures, MRI may be of value for showing localized bone edema and involvement of surrounding soft tissue, but fractures of the cortical bone may not be well demonstrated.\textsuperscript{5,4}

In the case of this patient, the initial standard view radiographs were interpreted as negative. Because the fracture was not displaced, cortical disruption was not evident. Additionally, superimposition of bony layers may have also contributed to the initial radiographs being interpreted as negative. Because of the suspicion of soft tissue involvement, MRI was the imaging modality chosen for further investigation with this patient. Although MRI is not sensitive to cortical disruption, it is extremely sensitive to demonstrating edema within bone, consistent with non-displaced fractures. Thus, while the advanced imaging in this case did not apparently match imaging decision making criteria, sufficient information was revealed to guide appropriate management of the patient.
INTERVENTIONS FOR HOOK OF HAMATE FRACTURES

Reported outcomes for patients with hook of the hamate fractures are restricted to results from case series because of the infrequency with which the injury occurs. Some authors have reported good outcomes with conservative management, but mal-union and non-union complications are more common after cast immobilization. In one case series, five of the six patients treated conservatively had non-union of the fractures. Additionally, because of the edges of the unhealed fracture, subsequent trauma to the flexor tendons and other surrounding soft tissues have also been reported as sequelae from failed conservative management. Finger movement, which may contribute to motion of the hook fracture fragment, may promote non-union. Additionally, suboptimal blood supply to the hook fracture fragment may lead to non-union and osteonecrosis.

Internal fixation has been described with satisfactory results although the procedures may be technically challenging for the surgeon. The use of both Kirschener wires and screw fixation have been described, both eventually leading to good outcomes. Most recently, a dorsal surgical approach has been described in order to minimize soft tissue trauma and reduce the risk of ulnar nerve injury. The need for surgical stabilization of hamate fractures is suggested to be greater when the fracture involves the body rather than the hook.

The most common course of action is the simple approach of excision of the hook fracture fragment. Most patients do quite well, with expected recovery to participation in premorbid activities. Residual grip strength deficits have been reported and have been theorized to be as a result of loss of the pulley mechanism for the ulnar-sided flexor tendons provided by the hook.

POST-OPERATIVE PHYSICAL THERAPY MANAGEMENT

At nine days post-operatively, physical therapy was initiated for this individual. The patient reported no symptoms in the wrist at rest and one of 10 on a numerical pain scale during activities of daily living and self-care. The pain was noted to increase, however, with full grasping and with the compressive forces often encountered when the hand was used to push. Active wrist motion was measured at 70 degrees each flexion and extension. Full motion was available in all digits. Grip strength of the affected hand was not initially measured because of the immediate prior removal of sutures and intolerance to pressure on the hypothenar eminence. Mild edema around the wrist was noted to be present along with tenderness in the area of the incision, now healing well.

The initial chosen interventions included Fluidotherapy® (Chattanooga Group, Inc., Hixson, TN), active wrist motion in flexion and extension, and tendon gliding exercises. One week later, his left wrist active range of motion had increased to 75 degrees extension and 85 degrees flexion. Left grip strength on this occasion was measured at 45 pounds. Additions to his course of care at this time included grasping of putty to improve grasping ability and soft tissue mobilization over and around the healed incision site.

At four weeks post-operatively, his grip in the affected hand measured 85 pounds. His wrist motion was unchanged from the prior visit. The recommendation to wear an occlusive dressing (Mepiform®, Mölnlycke Health Care, Gothenburg, Sweden) to assist in scar remodeling and reduction was added, which he wore for three weeks with daily changes of the dressing. He also used a mini-vibrator for 5-10 minutes three times per day for two weeks to assist in minimizing the scar sensitivity.

At approximately eight weeks from the time of surgery, he returned to playing golf, but had significant pain during and subsequent to that initial attempt. With the assistance of an external support (Wrist Widget™, Waimea, HI) directed at the ulnar aspect of the wrist (Figure 6), his tolerance to playing golf was dramatically improved within two weeks. He experienced a flare-up of his symptoms because of using his affected hand to brace a fall with an outstretched upper extremity. This exacerbation of symptoms from the fall persisted approximately three weeks.

OUTCOME

At six months post-operatively, he continues to report sensitivity of the proximal hypothenar region with direct application of pressure in specific circumstances, such as pushing through his hands on the arms of a chair when rising. Because of this persistent sensitivity,
he has adapted several tasks to minimize direct pressure application to the affected area. He has otherwise returned to his premorbid activities. Final grip strength measurement for the affected hand was 110 pounds. In the limited available literature on this topic, recovery time for return to daily activities following excision has been reported as approximately three to four weeks with return to sporting activities in six weeks.12,22 This patient required a greater period of time for recovery, potentially because of more than one problem existing at the time of initial presentation. The multiple soft tissue findings present on the MRI, including edema in multiple structures, ligamentous signal intensity changes, and degeneration of the triangular fibrocartilage, likely contributed to his delay in diagnosis as well as his extended rehabilitation.

At last report, the patient describes one to two rounds of playing golf without the preferred external support on the wrist as continuing to provoke ulnar wrist pain, but with a focus of pain different than that during the episode of the hook of the hamate fracture. Wear of the external support reportedly results in significantly greater pain control. The additional MR imaging findings of degeneration of the triangular fibrocartilage complex and its attachments along with the ligamentous changes are likely considerations in his remaining symptoms as tasks requiring axial compressive forces through the ulnar aspect of his wrist are typically irritating. Thus, his residual ulnar wrist pain may be arising from structures not directly related to the hamate fracture. This patient likely had more than one anatomical origin to his presenting symptoms. The pain originating from the hamate fracture appears to have been successfully managed overall, while those symptoms from the triangular fibrocartilage and neighboring structures are persisting and are problematic without external support.

**RECOMMENDATIONS**

The physical therapy evaluation of persistent ulnar-sided wrist pain in elite and recreational athletes using a racket, golf club, or similar implement should include the possibility of a subtle stress fracture or a more overt osseous disruption of the hook of the hamate in the differential diagnostic process. The patient may present with conventional radiographs in the postero-anterior and lateral views being interpreted as negative for fracture. These views, however, may be insensitive to revealing the most common type of hamate fracture at the base of the hook. Clinical suspicion may be further elevated with point tenderness with palpation of the hook of the hamate and with positive findings from the newly reported Pull Test. Specific radiographic views or supplementary CT imaging are often required to achieve differential diagnosis. With radiography, special views consisting of semi-supinated oblique and carpal tunnel projections are considered to be more revealing than standard views for this particular pathology. Computed tomography axial reconstructions of the wrist have the highest diagnostic accuracy for hook of the hamate fractures and should be considered if radiographs are negative or equivocal in the presence of a high index of suspicion based on the history and the clinical examination findings. This region is susceptible to multiple problems. Extensive clinical reasoning may be required to manage the symptoms and impairments with which patients may present.

**REFERENCES**


Clients presenting with ulnar-sided wrist pain can provide diagnostic and management challenges for physical therapists. Symptoms in this region may originate from multiple structures. Integration of clinical examination and diagnostic imaging results is often required for optimal decision-making and patient management. To obtain the most informative imaging results, practitioners need an understanding of injury patterns and their detection by various imaging modalities. This case describes a mature golfer who presented with persistent ulnar-sided wrist pain and was eventually determined to have a fracture of the hook of the hamate accompanied by neighboring soft tissue involvement also contributing to his symptom complex. His history and the diagnostic process are detailed along with a brief discussion of his subsequent management post-operatively.

**Level of Evidence:** 5 (Single Case Report)

**Key Words:** wrist pain, hamate fracture, golf injury

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INTRODUCTION

The hook or hamulus of the hamate arises palmarly as a curved process from the body of the bone and serves as a pulley for the fourth and fifth flexor tendons. The hook also provides a point of attachment for the flexor retinaculum at its peak. Other attachments include the flexor carpi ulnaris, flexor digiti minimi, and opponens digiti minimi. By virtue of these attachments, the hook of the hamate contributes to the borders of the carpal tunnel and tunnel of Guyon. The latter tunnel provides for passage of the ulnar artery and nerve to pass distally into the palmar aspect of the hand. From an embryological perspective, the body and the hook of the hamate develop separately before fusing at approximately 15 years of age. Occasionally, this fusion may not occur, resulting in an ossicle located volarly to the body of the bone. The presence of such an accessory ossicle can sometimes complicate interpretation of imaging, mimicking a fracture.

Fractures of the hook of the hamate are considered to be relatively rare. The reported frequency with which they occur, however, lacks current data. Some investigators suspect fractures of the hook of the hamate are increasing in frequency because of growing popularity of sports such as golf, baseball, tennis, and other racquet sports, increasingly played year-round. The onset of symptoms in many individuals may be a stress related sequence of events because of the repetitive grasping and loading of the hypothenar eminence with sports requiring an implement. In sports in which a racquet is held, the dominant hand is usually affected. In sports in which both hands grasp an object, the leading or non-dominant hand is most frequently affected. In addition to sports with a piece of equipment being grasped, hook of the hamate fractures have also been reported with rock climbing due to the repetitive grasping required in this activity. The mechanism of injury can also be macrotraumatic, such as falling on an outstretched hand or other direct trauma. Fractures of the hamate are generally classified as being Type I, involving the hook of the bone, and Type II, with the fracture line being in the body. Some authors further distinguish fractures based on the orientation of the fracture line within the body.

Correct diagnosis and management of ulnar-sided wrist pain can present a dilemma for the physical therapist. Among the causes of pain to be considered during the process of differential diagnosis are ulnar nerve injury, intercarpal instability, extensor carpi ulnaris tendon subluxation, tenosynovitis, triangular fibrocartilage complex injury, ulnar impaction syndrome, ulnar artery thrombosis, Kienböck’s disease, or potentially fractures of the regional osseous structures such as the ulnar styloid process, triquetrum, or hamate. Hook of the hamate fractures may be particularly difficult to identify because of the base of the hook of the hamate not being well visualized with the usual radiographic views and a lack of distinguishing findings on clinical examination. Understanding and integrating the patient's history, clinical examination findings, and diagnostic imaging indications and results are important for optimal decision making and patient management. In this case report, each of these aspects of the individual patient were informative in arriving at a correct diagnosis and guiding the course of care.

CLINICAL PRESENTATION

A 66 year-old retired male reported a 10 to 12 week history of left ulnar aspect wrist pain without recollection of a specific event initiating the pain. He noted the symptoms being present only intermittently during golf, specifically upon striking the golf ball. He was unaware of any symptoms during his daily activities otherwise. With rest and non-use of the involved hand, his symptoms would completely subside. With golf, however, the symptoms would occasionally reach 8 of a possible 10 on a verbal analog numerical pain scale (0 = no pain, 10 = extreme pain). In an attempt to manage his pain, he taped his wrist or used another form of an external support wrap.

On a particular occasion of playing golf in cooler weather, he struck the golf ball for a drive, experiencing a sudden, marked increase of pain. This exacerbation did not quickly subside and he was subsequently unable to continue playing. He began use of an over-the-counter wrist splint and sought care within the military medical system with which he was associated. Initial radiographs were ordered by a certified hand therapist (CHT) as the primary contact clinician. These radiographs, in posterior-anterior and lateral views, were interpreted as negative for fractures by a radiologist within the same medical system (Figures 1 and 2). At this time, mild edema was evident in the hypothenar region and along the ulnar aspect
of his wrist. Pain was reproduced with active ulnar deviation and passively in the same motion with overpressure, and also with active radial deviation, and with resisted wrist extension combined with ulnar deviation. Active wrist flexion and extension and the same passive motions with and without overpressure were of normal range and pain-free.

Palpation revealed mild to moderate diffuse tenderness and pain on the palmar and ulnar areas of the left wrist. This included along the ulnar collateral ligament, extensor carpi ulnaris, the hook of the hamate, and dorsally at the distal end of the ulna. Additionally, tenderness was noted in hypothenar region of the left palm, but localization was difficult because of acuity and the diffuse nature of the pain. Light touch sensation and two-point discrimination were noted to be intact and comparable to the unaffected hand. Grip strength was decreased as measured at 80 pounds on the affected left side and 160 pounds on the dominant right (Jamar® Hydraulic Hand Dynamometer # J00105, Lafayette Instrument Co., Lafayette IN).

Additional Imaging
Upon the patient’s consultation with an orthopedic surgeon, the decision was made to obtain magnetic resonance imaging (MRI) of the wrist for suspicion of injury to the triangular fibrocartilage complex. The MRI revealed, however, a nondisplaced fracture of unknown duration near the base of the hook of the hamate (Figure 3). On the T2-weighted MRI sequences, changes in signal intensity were also present surrounding the tendon of the extensor carpi ulnaris, suggesting inflammation of this structure. Also present was intermediate signal intensity degeneration of the scapholunate ligament and lunotriquetral ligaments without specific evidence of a tear or interval widening. These finding are consistent with degenerative change, but findings suggestive of instability were not present. The initially suspected origin of symptoms, the triangular fibrocartilage complex (TFCC), demonstrated degeneration, particularly at the ulnar attachments without evidence of a focal tear. Note the heterogenous signal intensity within

**Figure 1.** The initial posterior-anterior view radiograph of the patient’s symptomatic hand and wrist. Note the hook of the hamate cannot be well visualized from this view.

**Figure 2.** The initial lateral view radiograph also fails to allow adequate visualization of the hook of the hamate.
the TFCC and the fenestration of its attachments as demonstrated in Figure 4. There was also mild reactive marrow edema of the adjacent ulnar styloid.

Initial Management
Given the unknown age and nondisplacement of the hamate fracture accompanied by multiple soft tissue findings, a trial of conservative care was initially chosen. A six day course of methylprednisolone was prescribed to address inflammation and a custom-made splint was fabricated to limit wrist motion while allowing metacarpophalangeal motion. These interventions resulted in reduction of symptoms to a focus in the ulnar aspect of the wrist. At this time, further examination using the Pull Test resulted in provocation of pain at that specific focal area. The Pull Test as a specific clinical exam procedure has been proposed to screen for hook of the hamate fractures.\(^1\) For this exam procedure, the patient’s wrist is placed in full ulnar deviation with the digits of the involved hand flexed. The examiner then pulls distally on the fourth and fifth digits with the patient attempting to resist the examiner’s pull (Figure 5). If positive, the test will result in pain provocation in the patient’s wrist and palmar area. The focal area of pain is likely to be the hook of the hamate. The test has only been reported for its accuracy in a case series of five patients with exam results in all five matching computed tomography (CT) imaging.\(^1\) Psychometric values have yet to be established to determine its overall clinical utility. Additionally, palpation now similarly revealed isolated pain over the hook of the hamate as the surrounding tenderness had subsided. These clinical findings combined with the MRI results were viewed as confirmatory regarding the hook of the hamate fracture being the symptom origin.

One week later, the hook of the hamate was excised. Excision of the fractured hook of the hamate is the typical course of care for fractures at the base of the hook, and has been found to provide reasonably

Figure 3. An axial slice proton density weighted MRI image through the patient’s wrist reveals the nondisplaced fracture through the base of the hook of the hamate as suggested by the decreased signal intensity (darker region). Also note the proximity of the flexor tendons to the hook of the hamate.

Figure 4. MRI image demonstrating visualization of the triangular fibrocartilage complex, as noted in the colored oval.

Figure 5. The Pull Test. The patient flexes the fingers of the involved hand then the examiner attempts to pull the fingers distally out of the flexed position. A positive test is focal reproduction of pain at the area of the hamate.
good long-term results with few complications. Immediate post-operative care consisted of dressing for the wound and a protective splint.

**EVALUATION AND IMAGING**

The interview with the patient with a hook of the hamate fracture will usually be informative with regard to a history of onset of pain when swinging an implement such as a bat, golf club, or racquet. Rock climbing, as previously noted, has also been implicated as an activity precipitating similar symptoms. Palpation of the hook of the hamate is often most easily done by locating the pisiform and then moving one finger width distally and one finger width radially. Tenderness upon direct palpation of this structure is one of several findings that would raise suspicion of a possible fracture. Other findings could include palmar pain increased by grasping, pain with combined wrist extension and ulnar deviation, pain with flexion of the fourth and fifth digits (particularly when resisted), decreased grip strength, and paraesthesia of the fourth and fifth digits. Injury of the flexor tendons may also occur and may actually be the precipitating symptoms causing care to be sought. Accurate diagnosis often delayed with stress fractures because of the absence of trauma, despite persistent pain.

Particular clinical suspicion for the possibility of a hook of the hamate fracture may be appropriate when pain in the region persists with a history and exam findings as described above along with no diagnostic imaging or limited radiographic views. Unless a fracture of the hook of the hamate is specifically considered, the applicable radiographic views or more sensitive diagnostic imaging may not be completed. Posterior-anterior (PA) and lateral view radiographs of the wrist often do not reveal a discrete fracture line within the hamate. Thus, the interpretation of radiographs from conventional PA and lateral views as negative for fracture does not necessarily rule out the possibility of a fracture at the base of the hook. Carpal tunnel view radiographs have been advocated, but full wrist extension is required for the base of the hook to be visualized and may not be available because of pain. Additionally, identification of fractures has been reported using oblique view or modified semisupinated oblique view radiographs, if such positioning is tolerated. These views are described in the American College of Radiology (ACR) Appropriateness Criteria, which states that when fractures of the hook of the hamate are suspected, semi-supinated and carpal tunnel projections are indicated in addition to standard PA and lateral views of the wrist. Within the ACR Appropriateness Criteria, various forms of clinical presentations are described to provide evidence supported corresponding best imaging methodology. This taxonomy provides for levels of recommendations of indicated imaging modalities and their applications. Under Variant 8 of Hand and Wrist Trauma within the ACR Appropriateness Criteria, CT is recommended, if radiographs are equivocal in the presence of strong clinical suspicion. The additional radiographic special views and CT are each recommended at the highest level of 9, as being the most indicated. The multiplanar capabilities of CT provide for a greater level of accuracy in fracture detection. Radiography employing the special views has been described as having 80.5% to 90% accuracy in detecting hook of the hamate fractures, whereas CT has been noted to be 97.2% to 100% accurate. The axial CT views are often most revealing of the fracture. Additionally, CT can provide information as to the severity of displacement, if present, which may be valuable in decision making. In non-displaced fractures, MRI may be of value for showing localized bone edema and involvement of surrounding soft tissue, but fractures of the cortical bone may not be well demonstrated.

In the case of this patient, the initial standard view radiographs were interpreted as negative. Because the fracture was not displaced, cortical disruption was not evident. Additionally, superimposition of bony layers may have also contributed to the initial radiographs being interpreted as negative. Because of the suspicion of soft tissue involvement, MRI was the imaging modality chosen for further investigation with this patient. Although MRI is not sensitive to cortical disruption, it is extremely sensitive to demonstrating edema within bone, consistent with non-displaced fractures. Thus, while the advanced imaging in this case did not apparently match imaging decision making criteria, sufficient information was revealed to guide appropriate management of the patient.
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POST-OPERATIVE PHYSICAL THERAPY MANAGEMENT

At nine days post-operatively, physical therapy was initiated for this individual. The patient reported no symptoms in the wrist at rest and one of 10 on a numerical pain scale during activities of daily living and self-care. The pain was noted to increase, however, with full grasping and with the compressive forces often encountered when the hand was used to push. Active wrist motion was measured at 70 degrees each flexion and extension. Full motion was available in all digits. Grip strength of the affected hand was not initially measured because of the immediate prior removal of sutures and intolerance to pressure on the hypothenar eminence. Mild edema around the wrist was noted to be present along with tenderness in the area of the incision, now healing well.

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OUTCOME

At six months post-operatively, he continues to report sensitivity of the proximal hypothenar region with direct application of pressure in specific circumstances, such as pushing through his hands on the arms of a chair when rising. Because of this persistent sensitivity,
he has adapted several tasks to minimize direct pressure application to the affected area. He has otherwise returned to his premorbid activities. Final grip strength measurement for the affected hand was 110 pounds. In the limited available literature on this topic, recovery time for return to daily activities following excision has been reported as approximately three to four weeks with return to sporting activities in six weeks.\textsuperscript{12,22} This patient required a greater period of time for recovery, potentially because of more than one problem existing at the time of initial presentation. The multiple soft tissue findings present on the MRI, including edema in multiple structures, ligamentous signal intensity changes, and degeneration of the triangular fibrocartilage, likely contributed to his delay in diagnosis as well as his extended rehabilitation.

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**RECOMMENDATIONS**

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**REFERENCES**


ABSTRACT
Currently, the popular approach to post-concussion management of the athlete relies upon the use of a multi-disciplinary team of healthcare providers, all typically coordinated by a physician. That core team is often supplemented by nurses, psychotherapists, coaches, teachers, the athletic director, and, of course, family members. However, access to such a model is frequently limited by financial, geographical, and numerous other factors. In the absence of such resources, a thorough clinical evaluation and management by an available, ongoing healthcare provider, quite often the sports physical therapist, becomes necessary.

The authors recommend that the professional who coordinates the athlete’s post-concussion healthcare should focus efforts upon a comprehensive assessment and tailored treatment plan specific to the athlete’s post-concussive symptoms. Assessment of both pre-morbid function and post-injury physical, cognitive, psychosocial, emotional, and behavioral issues, including the patient’s support system, can assist the clinician with identifying specific constraints to sport, academic, social, and vocational activity participation. Hence, the assessment provides structure to the athlete’s individualized treatment plan. Successful specialized interventions that address the multi-faceted impairments of sport related concussion frequently require knowledge of resources in a variety of other healthcare professions, in order to facilitate appropriate and necessary treatment referrals.

Initial assessment should be followed by repeat monitoring throughout treatment, and spanning a variety of environments, in order to ensure the athlete’s full recovery prior to return, not only to sport participation, but also to involvement in social, academic, and/or employment related life activities.

Level of Evidence: 5

Key Words: evaluation, rehabilitation, sport concussion

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BACKGROUND
The Centers for Disease Control and Prevention estimates that over three million traumatic brain injuries related to sport injuries occur annually. Conussion, or mild traumatic brain injury (mTBI), describes the majority of these occurrences. This injury is defined as a complex, pathophysiological process, affecting the brain, induced by traumatic biomechanical forces to the head, in the form of a blow and/or subjection to acceleration/deceleration forces that may or may not involve loss of consciousness.

However, obtaining sound data concerning the global incidence of sport concussions is complicated by incongruence in injury reporting and diagnosis. Many athletes with concussions never make it to the emergency room, but are treated on the sideline and in the clinic. Further, research suggests that athletes frequently underreport concussive symptoms and/or that the symptoms are unrecognized. Injury reporting and diagnostic inconsistencies produce challenges for the health care providers who manage athletes with sport concussion. Athletes with concussion rapidly develop short-term impairment of neurologic function; among those, 80 to 90% resolve spontaneously within the first ten days, although the recovery timeframe may be longer in children and adolescents than in their adult counterparts.

However, a small percentage of patients experience prolonged, physical, behavioral, neuropsychological, and/or personality changes frequently termed post-concussive syndrome (PCS). However, PCS are not unique to mTBI. For example, the symptoms occur frequently in day to day life among healthy individuals and persons with other conditions such as chronic pain or depression. Reports of incidence and prevalence of individuals who suffer with PCS vary, due in part to the disparities in defining PCS. For example, the outcome measure(s) for PCS are often symptom checklists rather than uniform, criterion based diagnoses. Researchers remain inconsistent in their efforts to define the point in time at which initial concussion symptoms become post-concussive syndrome. For purposes of the current concussion management recommendations contained in this clinical commentary, the authors discourage the use of post-concussion syndrome as a diagnosis. Rather, the clinician(s) should identify and document the unique patterns of persistent post-concussion symptoms (defined as the cluster of symptoms persisting beyond the first ten days post-injury) exhibited during physical, psychological, and neuropsychological examinations and focus on amelioration of the symptoms.

Evidence is evolving toward establishing the efficacy of medical and behavioral interventions for post-concussive symptoms. Concussion management is moving toward an individualized, patient centered approach to assessment and treatment. A wide range of health and other professionals are involved in the care and the provision of services of athletes after concussion, including the physician, sports physical therapist, athletic trainer, neuropsychologist, and speech-language pathologist, functioning as a core medical team. Academic and employment personnel are also crucial to concussion management, including the nurse, social worker/guidance counselor, teacher, coach, athletic director, and family.

One of the most critical and controversial questions within the medical community is when an athlete should be allowed to safely return to sport after a concussion. Another vital issue often neglected in the literature of sport concussion management is the decision making process used to support the athlete's successful return to academic, employment, and social activities. In this clinical commentary, the authors synthesize the current literature pertaining to on-field/sideline and clinic management of athletes with sport concussion. Specific dilemmas in the context of return to play and return to play decision making and resource allocation are also explored. Recognizing that this analysis is restricted, the authors hope to encourage future dialogue regarding comprehensive management of athletes with sport concussion(s).

Preseason Baseline Testing
Baseline concussion testing is often mandated for participation in many sports, including football and hockey, from elementary school to the professional level. Such testing is intended to be brief and to measure selected brain processes such as balance, somatic and neurobehavioral symptoms, attention span, working memory, and reaction time. Clinical tools for baseline assessment include the
Sport Concussion Assessment Tool-2 [SCAT2], Clinical Reaction Time, the Digit Symbol Substitution Test, and, most recently, computerized tests. In the event that an athlete suffers a concussion, he/she then retakes the test(s). Baseline test performance is next compared to scores obtained post-concussion, in an effort to determine the extent of the injury and the athlete's level of brain function recovery. Typically, the patient is not allowed to return to participation until the score returns to baseline. However, the reliability, validity, and feasibility of baseline testing remain questionable. Bailey and colleagues suggest that athletes may perform below their highest potential during pre-season baseline neuropsychological testing, creating a low threshold for comparison if they are then re-evaluated for return to play, post-concussion. Biopsychosocial factors such as age, gender, headache, education level, learning disability/attention deficit disorder, and psychiatric conditions have been suggested to influence baseline scores. In addition, testing environment, for example, distracted, isolated, or supportive settings, may also affect baseline scores. Therefore, obtaining valid baseline and comparative post-injury scores that are interpreted in a clinical context is crucial for sport concussion management. However, many leagues may not have access to the appropriate resources to conduct baseline testing; hence, concussion management protocols should be employable without baseline data. Schmidt and colleagues have reported on the clinical utility of standardized normative scores when baseline data is unavailable.

On-field/Sideline Assessment

The timeline for the initial assessment of concussion begins with the onset of the injury. The brain, head, and neck are the involved body structures in a concussion, and should all be evaluated. The medical team that is first to assess the injured athlete should always remember that the unconscious athlete must be treated as having a possible cervical spine injury. Experts agree that no single instrument should be used in isolation to diagnose concussion, nor should one be used to evaluate the athlete's recovery. When a player demonstrates any feature of a concussion, he/she should be removed from play and assessed by a healthcare provider trained in acute concussion management. Subsequently, the “On-field or sideline evaluation of acute concussion” (pp. 756-757) guidelines from the Consensus Statement on Concussion in Sport should be implemented.

The suspected diagnosis of concussion may include one or more of the five clinical domains, (a) somatic (e.g., headache) and/or emotional symptoms (e.g., lability), (b) physical signs (e.g., loss of consciousness or amnesia), (c) behavioral changes (e.g., irritability), (d) cognitive impairment (e.g., slow to answer questions or follow instructions and/or slowed reaction time), and/or (e) sleep disturbance (e.g., drowsiness). A panel of experts in sports medicine and concussion management have recommended specific tests, appropriate for use during the sideline evaluation, including the Sports Concussion Assessment Tool (SCAT 2), or the Maddocks questions, and the Standard Assessment of Concussion (SAC).

Although the SCAT 2 has not yet been validated, use of this instrument for field assessment of concussion is the international norm, and clinicians are encouraged to use the tool to promote consistency in clinical concussion assessment. Following administration of the SCAT 2, the team physician must decide whether there is any indication for referral to a hospital, or whether the player may be adequately managed at home. Specific neurological indicators that warrant emergent referral to a hospital include vomiting, dizziness, worsening headache, severe neck pain, double vision, difficulty recognizing people or places, weakness/numbness in limbs, increasing confusion or irritability, slurred speech, seizure, or excessive drowsiness. Home supervision requires that a responsible adult be present to monitor the athlete over the next 24 to 48 hours.

The athlete's symptoms should be monitored regularly using a symptom checklist and red flag indicators such as those indicated on the Acute Concussion Evaluation (ACE). It should be recognized that the appearance of symptoms can be delayed for several hours following a concussive episode. Concussion diagnosis is often complicated by the athlete's attempt to mask his or her condition, in order to continue to play; therefore, a medical team with experience in sports medicine and sport related concussion management should be consulted. Current principles of sport concussion in the sport concussion management...
protocol indicate that return-to-play decisions require serial medical evaluations and should not be made merely after the initial sideline and/or emergency room evaluations. Contemporary medical management, including many state laws that represent the main principles of the Zachery Lystedt model legislation, prohibits the return of a concussed athlete to participation on the day of injury.

Follow-Up/Referral
Often, no appropriate healthcare provider is present on the field to perform the initial evaluation. As an additional point of first contact following injury, the athlete may present to the emergency room, physician's office, or another care provider (e.g., the sports physical therapist). Typically, multiple systems are affected by sport concussion; hence, a comprehensive assessment by a rehabilitation specialist is crucial to determine the athlete's individual needs and to rehabilitate the athlete.

A contemporary approach to sport concussion management is the use of a multi-disciplinary network of medical professionals with skills in assessment and rehabilitation of individuals with head injury, coordinated by a primary care sports medicine physician. Input from psychiatrists, neurologists, neurosurgeons, neuropsychologists, speech-language pathologists and, of course, sports physical therapists should be accessed for specific indications.

Although symptoms of concussion may appear mild, they can significantly negatively impact the individual's ability to function physically, cognitively, and psychosocially. A careful clinical interview concerning premorbid functioning is needed to determine previous learning disabilities, concussion history, academic history, any history of problems with social behavior, work history, any history of concomitant substance abuse, and the athlete's level of competence and independence prior to the injury. Such factors can assist the clinician in providing better estimates of the athlete's functional capacity and limitations.

Both recreational and professional athletes participate in a variety of activities, including sport, academia, employment, and social events. Research suggests that athletes often report dizziness, reduced balance, headache, and reduced physical activity tolerance following concussion, any of which can interfere with participation in a myriad of activities. Hence, sports physical therapy consultation is frequently warranted.

A comprehensive assessment of the athlete, post-concussion, should include not only an assessment of function(s) and activity participation, but also an evaluation of that patient's support systems (e.g., family, friends, academia, employment, and access to technology). Such systems may provide necessary resources and/or hinder the athlete's successful return to participation in sport, cognitive, and psychosocial activities. Specific questions to guide the assessment of activity participation are presented in Activity Participation Assessment VA mTBI management reference.

The comprehensive assessment will guide the sports physical therapist's management of not only neuro-musculoskeletal, balance, vestibular, and/or visual functions, but also the host of cognitive and psychosocial symptoms associated with concussion. Initiation of early intervention and education is essential to the athlete's recovery. During initial and subsequent contact with the athlete, the clinician should provide that patient and his/her family with education concerning typical post-concussive symptoms, transient effects of head injury, signs of stress, suggestions regarding how to cope with them, and a plan for supervised, gradual resumption of pre-injury activities. When the injured athlete's needs exceed the scope of practice of the sports physical therapist, referrals for consultations with appropriate specialists such as neuropsychologist, speech-language pathologist/cognitive therapist, audiologist, neuro-opthalmologist/optometrist, and/or psychiatrist, should be recommended in the plan of care. Sports physical therapists who manage athletes post-concussion should be competent in assessment and intervention techniques associated with vestibular function, headache management, postural stability, balance, and physical activity, not only to support return to play, but also to facilitate return to life participation.

Postural Stability and Balance Assessment
Impaired postural control is common among athletes with post-concussion symptoms. Postural stability testing is a useful tool for objectively assessing the
and/or musculoskeletal disorders. Clinical presentation of dizziness may include dysfunction of the vestibular system, muscle power, gait pattern, proprioception, perception, vision, and blood pressure regulation. Thus, in order to identify appropriate intervention modalities, it is essential to determine the primary cause of dizziness. Physical therapists can assist in differential diagnosis by performing thorough neuromusculoskeletal and vestibular assessments. Activities that can be affected by dizziness include ambulation safety and endurance, academic performance, ability to socialize, work tolerance, and sport participation. Vestibulo-ocular reflex training (gaze stability training) and various canalith repositioning maneuvers are among the interventions used in treatment of dizziness. However, such management programs are few, with sparse, and often contradictory, findings which interfere with translation to clinical practice.

Post-traumatic headache is the most common post-concussive symptom of sport-related concussion. The International Headache Society’s classification category involves secondary headaches, associated with head and neck trauma. The four most common patterns of post-traumatic headache are tension-type headaches (including a cervicogenic component), migraine headaches, combined migraine and tension-type headaches, and headache due to cognitive fatigue. Sports physical therapists who provide comprehensive assessment of the neuromusculoskeletal system for the athlete complaining of headache can facilitate differential diagnosis of the pattern of the headaches and expedite tailored intervention for that individual. However, confirmatory studies of specific guidelines for post-traumatic headache management among athletes are lacking. Currently, guidelines are offered for post-traumatic headache management based upon primary headache categories and treatments.

Headache

Body dysfunctions that may exacerbate/trigger a headache include cervical spine injury, impaired sleep, higher-level cognition, vision, hearing sensitivity, and exercise. Headaches may then impair other body functions and activities, including energy and drive, sleep, attention, emotion, thought, higher-level cognition, exercise tolerance, and appetite. Sports physical therapists who provide comprehensive assessment of the neuromusculoskeletal system for the athlete complaining of headache can facilitate differential diagnosis of the pattern of the headaches and expedite tailored intervention for that individual. However, confirmatory studies of specific guidelines for post-traumatic headache management among athletes are lacking. Currently, guidelines are offered for post-traumatic headache management based upon primary headache categories and treatments.

Post-Concussion Dizziness

More than 23 percent of patients with acute sport concussion present with the complaint of dizziness. The etiology of dizziness in concussion includes inner ear disorders (e.g., benign paroxysmal positional vertigo, labyrinthine concussion, and/or perilymphatic fistula), central nervous system disorders (e.g., post-traumatic migraine, brainstem concussion, autonomic dysregulation/postural hypotension, oculeomotor abnormalities and/or seizures), and psychological motor domain of neurologic functioning. One possible etiology of postural dysfunction is disruption of the ability to utilize and process vestibular information. Specific assessments for postural function include dynamic posturography, the Sensory Organization Test, and the Clinical Test for Sensory Interaction in Balance which require the SMART Balance Master. The Balance Error Scoring System is also an assessment of postural function and requires minimal inexpensive equipment compared to the SMART Balance Master. Feasible balance measures include the Dynamic Gait Index, the Functional Gait Assessment, the HiMAT, Dual Cognitive Task paradigms, and Five Times Sit to Stand. The body functions that directly influence postural stability and balance include the vestibular system, sensations associated with hearing and vestibular functions, the proprioceptive system, mobility of joints, muscle power, muscle tone, and gait pattern. Examples of activities subject to disruption from postural instability include ambulation safety and endurance, climbing, some employment related activities and, of course, most, if not all, forms of sport participation. Intervention techniques that may improve postural stability across activities include sensory integration exercises, balance training, oculomotor training, eye-head coordination training, visual motion sensitivity training, neuromuscular control, and body mechanics and posture. However, there is limited evidence in the rehabilitation literature in support of the positive effects of physical therapy interventions on balance and mobility outcomes. Further, there is considerable variability in the intensity, duration, and frequency of the interventions reported in the literature, therefore, presenting a considerable challenge to extrapolating meaningful clinical guidelines.

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conducted to inform clinicians concerning the management and prevention of chronic, post-traumatic headache, in order to minimize the athlete’s disability.

Physical Activity Tolerance
Managing athletes with post-concussive symptoms in order to achieve and maintain optimal physical function presents a considerable challenge due to sparse scientific evidence to guide clinical practice. Current international guidelines indicate physical activity should be avoided until an athlete is asymptomatic at rest. However, inactivity can contribute to the disease process of several of the co-morbidities that are associated with concussion, such as vestibular disorders, depression, posttraumatic stress disorder, chronic fatigue, and pain disorders. Three to six days of bed rest can result in an athlete’s complaint of headache, restlessness, and difficulty sleeping, which may complicate the treatment of the patient with persistent post-concussion symptoms. As with many other medical conditions, the role of physical activity in the treatment of concussion needs to be reconsidered.

There are legitimate reasons to refrain from activity after a concussion. First and foremost the injured athlete should be removed from play and examined for the presence of life threatening injuries, such as bleeding in the brain. After life-threatening injuries have been ruled out and the diagnosis of a concussion has been made, restricted activity is prescribed to avoid re-injury. There appears to be a 7-10 day period of a heightened susceptibility to re-injury. Removal from activity during this timeframe is essential to reduce the risks of persistent symptoms and the development of second impact syndrome that can accompany repeat concussions. The authors recommend that clinicians respect this period of decreased activity. No sport participation should occur during this time; however, general physical activity deserves further consideration.

Recently, the utility of the universal recommendation for complete rest until asymptomatic after concussion has been questioned. Theoretically, after an athlete suffers a concussion, the sympathetic nervous system activity is exaggerated and heart rate is increased, possibly due to disrupted cerebral blood flow. Such factors can contribute to the re-expression and/or exacerbation of post-concussion symptoms with physical exertion or other stressors that result in an increase in blood pressure. Sub-symptom threshold exercise may be a method to treat the disrupted blood flow and alleviate the dysfunctional sympathetic nervous activity.

Research suggests that sub-symptom threshold cardiovascular exercise and gradual progression of exertion with heart rate monitoring may be effective interventions in order to rehabilitate an athlete with persistent concussion symptoms. The majority of medical and activity tolerance guidelines pertain to sporting activities, and not necessarily to exercise. It has been suggested that returning to pre-injury activities within days to weeks post-injury, regardless of symptoms, is likely to speed up, rather than slow down recovery. Current recommendations regarding the role of physical activity in concussions are as follows:

- Bed rest exceeding 3 days is not recommended
- Gradual resumption of preinjury activities should begin as soon as tolerated
- Contact and activities with high concussion exposure should be avoided for at least 1 week (7 days)
- Patients should take part in activity as guided by their symptoms. If symptoms are exacerbated, then a reduction in the physical and/or cognitive demands should occur and the return to activity should take place at a slower pace
- 1 month post injury, a supervised exercise program should be considered as part of the treatment plan for individuals who are symptomatic

Clearly, the aforementioned recent physical activity recommendations conflict with the current internationally accepted guidelines of concussion management. However, the recommendations can also be viewed as the evolution of concussion management that fully supports a patient centered method of rehabilitation. What follows is a summary of the current literature for the assessment and progression of physical activity among athletes post-concussion and clinical application.

Physical Activity Tolerance Assessment
Prior to initiation of any physical activity (walking, biking, jogging, running, etc.), an athlete who has
suffered a concussion should participate in detailed, serial examinations with the medical team to determine readiness for physical activity. In all cases the managing physician should medically clear physical activity participation before any initiation of activity is started. In the situation where the patient has demonstrated recovery from symptoms, and the goal is to return to play, the authors have found previously published gradual return to play protocols to be effective. However, the small portion of patients who develop persistent post-concussive symptoms do not fit into current guidelines, thus necessitating the development of new assessment and intervention strategies. The authors recommend that clinicians who treat those with persistent post-concussive symptoms consider a physical activity assessment and intervention approximately one month post-injury.

The suggested protocol for the activity tolerance assessment includes the use of the Balke treadmill test with ratings of perceived exertion (the Borg 15 point scale). Ideally, a heart rate monitor and treadmill that can be inclined are the equipment requirements for the initial assessment of exercise activity tolerance. The athlete’s baseline of perceived exertion rating and number of concussion symptoms should be recorded prior to physical activity.

The Balke treadmill protocol differs for males and females and is as follows. For males, the treadmill is set at 3.3 MPH at a grade of 0%. After one minute of activity the grade is increased to 2% and every minute thereafter the grade is increased 1%. Females begin with the treadmill set at 3.0 MPH and a grade of 0%. The grade is increased 2.5% every 3 minutes. For both sexes the grade is increased until the patient is unable to continue activity due to symptom exacerbation or fatigue, at which point the test is terminated. The clinician should record the speed, grade, and heart rate associated with symptom exacerbation and/or fatigue. Hence, the heart rate associated with symptom exacerbation and/or fatigue provides the athlete’s heart rate threshold (HRT) to guide physical activity interventions.

Realistically, the Balke protocol may not be a feasible option due to equipment limitations. For example, the authors have initiated pilot investigations of the feasibility of using the Balke protocol with concussed athletes in a clinical setting. Preliminary data suggests the Balke protocol is impractical because the athlete’s physical activity tolerance post-concussion exceeded the equipment capabilities. Specifically, the incline limitation of the treadmill was 10%, which was insufficient for the patients to reach fatigue, heart rate maximum, and/or symptom exacerbation. Subsequently, the clinician modified the Balke protocol by increasing the walking speed by 0.5 MPH after every 3 minutes in order to obtain the requisite heart rate threshold.

**Physical Activity Tolerance Intervention**

After medical clearance is obtained, and using the HRT determined from the steps above, a cardiovascular exercise prescription can be formulated. The authors suggest that exercise intensity can begin at <70% of the HRT for 15 minutes. Initially exercise time should be increased 5 minutes each session until a total time of 30 minutes is reached. After a total of 30 minutes of exercise is reached exercise intensity can be increased by approximately 5% increases in heart rate each session. These are general guidelines. The most important principle is to tailor the exercise to the individual and progress only when appropriate. The challenge to clinicians is determining the point when progression is appropriate, especially when symptoms may be present. The authors suggest that exercise may be continued and progressed as long that there is no symptom increase above baseline.

Clinicians should also keep in mind alternative exercise protocols and not simply continuous cardiovascular exercise. There may be times when individuals tolerate interval training better than continuous exercise. This would allow for a rest period or decreased activity rather than simply exercising through symptoms, which may not increase during exercise, but interfere with the patients’ exercise adherence.

The individual undergoing physical rehabilitation needs to be supervised and monitored during and after activity for the development of neurobehavioral and somatic symptoms. If symptoms develop during the exercise, the clinician should guide the athlete to immediately decrease the demands of the exercise until symptoms resolve. When symptoms persist with a decrease in activity intensity, the activity should be terminated. The exercising heart rate and
the duration of exercise when symptoms develop should be recorded, and used to tailor future exercise prescriptions. Future exercise should be modified so who has the HRT and the time of exercise is lowered, or divided into intervals. The athlete should also be monitored for 30 minutes post exercise for the development and/or exacerbation of any symptoms.

While exercise in general is suggested as a treatment modality,92,96,97 there is sparse evidence to support the use of resistance training. Clearly, cardiovascular exercise can be helpful in the treatment of many of the comorbidities associated with concussion. Resistance training may also support recovery; however, current guidelines do not exist and are beyond the scope of this article. Currently, the authors recommend cardiovascular exercise rather than resistance training, with the acknowledgement that future research may find a benefit of resistance training.

Future studies should identify effective and feasible HRT protocols to investigate the applicability of HRT to measure physical activity tolerance after brain trauma, specifically among athletes who endure one and/or repeated concussions. Further research should also evaluate athletes’ HRT during pre-participation physicals to establish normative data. Moreover, investigations of the effects of resistive training on the recovery rate of an athlete after sustaining concussion(s) are warranted in order to guide effective, comprehensive medical management.

Cognitive Activity Assessment
Cognitive symptoms typical of mTBI include difficulty with concentration and attention, memory problems, executive dysfunction, and slowed mental processing.9,30,102,103 Typically, the neuropsychologist is responsible for the comprehensive evaluation of cognitive functioning, attempting to relate cognitive and behavioral findings to the underlying brain systems involved. The Zurich guidelines state that trained neuropsychologists are in the best position to interpret neuropsychological tests, but stress that this may not always be possible.2 Consequently, other medical professionals, such as the speech-language pathologist, may provide an assessment of cognitive-communication function and provide appropriate intervention recommendations. However, multidisciplinary input from neuropsychologists and/or speech-language pathologists is not always available. Therefore, the involvement of sports physical therapists is critically important to recognize and address cognitive and motor impairments associated with sport related concussion. Prior to initiation of any cognitive training exercise, an athlete that suffered a concussion should be evaluated by his/her physician and obtain medical clearance to participate in cognitive training exercise.

One method of examining cognitive function involves conducting a structured interview with the athlete, in order to elicit a list of cognitively based problems that may be interfering with everyday function. For example, the athlete may report difficulty driving, frequently forgetting information in conversations, difficulty tolerating distractions, slowness or errors in academia or the workplace, and/or fatigue.4,104 From the problem list, the sports physical therapist can garner insight into the individual’s awareness of his/her impairments, determine the extent and nature of functional problems, and develop strategies for responding to the problems. Hence, goals can be tailored to functional terms that are mutually discussed and agreed upon.4 Specific clinical tasks used to examine attention and other executive functions among athletes include the Trail Making Test,41,102 cancellation tasks,28 the Digit-Symbol Substitution Test,28-30 and dual-task paradigms.8,74,75,105,106

Dual-task paradigms are particularly relevant for the physical therapist due to their association with abnormalities in gait and other functional limitations.62,74,75,105 With reliable and valid outcome measures using dual-task conditions, therapists can accurately identify dual-task performance problems and fall risk, establish guidelines for intervention, and judge whether the intervention is effective in improving dual-task performance. Dual-task paradigms also share theoretical principles with the divided attention clinical model.4 The disruptions in task performance observed during dual-task conditions are thought to be due to insufficient executive capacity to share attention between the demands of the tasks.107 The equation for calculating the dual-task cost is [(dual-task performance – single-task performance)/ single-task performance] × 100.108 Dual-task costs represent the percent difference between single-task and dual-task conditions.

Gentile108-110 and McCulloch111 suggest that therapists should match the patient’s motor, visual, and cognitive
abilities to the types of tasks used for dual-task performance, so that the tasks are feasible for patients to perform in the single-task condition. A structured approach to monitoring errors in performance of motor and cognitive tasks can guide decision making regarding when to increase task difficulty. For example, the authors initiated a pilot investigation of the dual-task cost or divided attention function among high school and collegiate athletes who suffered one or repeated concussions. The dual-task paradigm was defined as tandem stance on a solid surface maintained by the student-athlete for 20 sec with his/her eyes closed while completing simple calculations by subtracting seven from 100 and then from his/her subsequent answers. Outcome measures included balance errors using the Balance Error Scoring System (BESS) and correct number of subtractions. Preliminary results suggest that the student-athletes demonstrated an increase in the number of balance and cognitive errors with slower processing speed during dual-task compared to single-task performance. During the dual-task assessment, the student-athletes also provided subjective reports of significant difficulty attending to class lectures and to assignments. Subjective reports also included increased level of stress associated with the change in academic activity tolerance/participation compared to performance prior to the concussion. What follows is a brief summary of one specific dual-task paradigm developed by a speech-language pathologist to support a student-athlete’s successful return to academic participation.

The necessary equipment to complete the dual-task paradigm assessment includes a structured interview and ratings of attention function,4 neurobehavioral and somatic graded symptom checklist,18,25,40,112,113 two copies of functional reading material selected by the athlete (e.g., articles and books from class assignments), pencil, and timer. The dual-task design could be defined as a functional reading task (articles and books from enrolled classes) for comprehension and simultaneously scanning for a target word (and). Baseline symptoms were recorded prior to initiating the reading task for comprehension and simultaneously scanning for a target word (e.g., while reading, the athlete counted the number of ands). Single-task was defined as reading comprehension in a quiet clinical setting. Outcome measures for the single and dual task included efficiency and accuracy measures. Specifically, the number of pages read, tolerance duration (e.g., duration until trigger or exacerbation of neurobehavioral and/or somatic symptoms), the number of correct targets (and), the number of errors (errors of omission and commission), and the number of correct responses to concrete comprehension questions. Dual-task costs were calculated and analyzed to estimate the magnitude of attention impairment during a divided attention task. The athlete’s tolerance duration was also recorded.

Results from all of the assessment components (e.g., questionnaires, ratings of attention, and dual-task cost) were utilized to guide the prescribed tailored interventions to gradually increase asymptomatic attention capacity across various settings (clinic, school, social events). Baseline attention capacity varied among each student athlete ranging from five minutes to 30 minutes, which supports the patient centered approach for rehabilitation of function after suffering a concussion. However, confirmatory studies that support specific tasks for dual-task assessment are lacking. This problem is due in part to the paucity of literature addressing dual-task performance among athletes, and to the disparity in study designs (e.g., variables measured and outcome measures chosen). Additional research that targets clinical dual-task measures among athletes (amateur and professional) who have suffered a concussion is vital to guide effective clinical management.

Cognitive Activity Intervention

Most guidelines for management of concussion in sport use vague, graded exercise approaches, with a focus upon return to play, often neglecting guidelines that support return to cognitive and psychosocial activities.2,3,96-98 The sports physical therapist should be able to include cognitive tasks within the athlete’s plan of care in order to facilitate the athlete’s care and comprehensive rehabilitation post-concussion. In some instances, cognitive impairments may require restricted activity or reduced environmental challenges in order to maintain safety, facilitate participation, and/or optimize therapy activity. For example, Table 1 provides examples of accommodations to support successful return to school and/or work following concussion, with a focus on minimizing the trigger of somatic and neurological symptoms.14,115

Currently, limited information exists to guide treatment addressing the use of cognitive tasks as a part of the physical intervention. The use of dual- or multi-
ple-task conditions simulates real life, so that patients can learn strategies to attend to safety, even in the presence of distractions. For example, Gentile's taxonomy\(^{108-110}\) is a useful tool to assist the sports physical therapist in the development an environment for successful skill practice at individual skill levels. The taxonomy consists of sixteen sequenced task categories. The demands of the athlete generally become increasingly complex with manipulation of the environmental context in which the skill takes place and the function the motor skill must fulfill. The ability to generalize novel, dual-task conditions to real life has not been demonstrated for athletes with sport related concussion, so choosing therapy activities that simulate real life is a reasonable approach.

For example, reconsider the pilot investigation of a dual-task paradigm during the speech-language session. The same equipment that was used during assessment was utilized during intervention with a gradual, tailored increase in the duration of the activity. Specifically, attention training capacity during the divided attention task started at the sub-threshold cognitive activity tolerance. The formula for calculating sub-threshold cognitive activity tolerance is (tolerance duration during dual-task \(\times 60\%\)). Sixty percent was derived from the graded return-to-play recommendations.\(^2\)

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<td></td>
<td>Provide note-taker/scribe</td>
</tr>
<tr>
<td></td>
<td>Provide classroom/meeting notes/PowerPoint prior to lecture/meeting</td>
</tr>
<tr>
<td></td>
<td>Preferential classroom seating</td>
</tr>
<tr>
<td>Photophobia</td>
<td>Ball cap</td>
</tr>
<tr>
<td></td>
<td>Sunglasses</td>
</tr>
<tr>
<td>Sonophobia</td>
<td>Dimmer lights</td>
</tr>
<tr>
<td></td>
<td>Excuse from assemblies, band, orchestra, woodshop, conferences</td>
</tr>
<tr>
<td></td>
<td>Earplugs</td>
</tr>
<tr>
<td></td>
<td>Lunch in a quiet area</td>
</tr>
<tr>
<td>Slow to answer/follow directions</td>
<td>Extra time for assignment completion</td>
</tr>
<tr>
<td></td>
<td>Extra time testing</td>
</tr>
<tr>
<td>Difficulty Remembering</td>
<td>Postpone or stagger testing</td>
</tr>
<tr>
<td></td>
<td>Excuse from standardized testing</td>
</tr>
<tr>
<td></td>
<td><strong>Assistive Technology:</strong> Smartphone/Electronic Notebook/Software Applications</td>
</tr>
<tr>
<td></td>
<td>Alarms</td>
</tr>
<tr>
<td></td>
<td>Minimize the number of academic courses/work assignments and projects</td>
</tr>
</tbody>
</table>

Based on the structured interview, the student-athletes reported significant difficulty with daily class participation. Typically, classes were reported to last for 60 min in duration. Hence, a long-term goal of 60 min of cognitive activity using dual-task design was set. Initially, the athletes completed the same dual-task with different reading material for the sub-threshold duration. Gradually the duration was increased by 5% thereafter, guided by the athlete’s activity tolerance. If the athlete demonstrated and/or reported trigger or exacerbation of symptoms during task participation, the clinician immediately decreased the duration and cognitive load (e.g., transitioned to less cognitive-demanding task). For example, the cognitive task was aborted and teaching of...
cognitive behavioral techniques (e.g., neck stretches, mobility, and relaxation techniques) to ameliorate the symptoms. The student-athlete was trained to initiate cognitive behavioral techniques upon symptom onset to support carry-over of the strategies in natural environments. Symptoms were monitored until they returned to baseline status. Once symptoms returned to baseline status, the dual-task intervention was initiated again using the last asymptomatic cognitive activity tolerance and increased as tolerated.

Other dual-task treatments may include combinations of motor tasks specific to the athlete's sport participation (walking and carrying items or walking while performing dribbling drills) and combinations of motor tasks with other cognitive tasks (conversation, list making or way finding) within various environments (clinic, gym with few individuals or gym during team practice). Cognitive rehabilitation can also be integrated into physical therapy sessions through training and practice of functional multistep routines, and use of external cognitive aids (smart phones, electronic notebooks or alarms) to assist with the athlete's organization, management of events, deadlines, medication, metacognitive strategies, and social skills training.4,115,116

Undoubtedly, additional study of patients with neurologic involvement, specifically athletes who have suffered one or more concussions, is necessary to understand how attention and allocation of attention affect community, academia, and employment participation. As knowledge of the extent and nature of these problems expands, appropriate intervention strategies should also become evident.

SUMMARY AND CONCLUSIONS

The brain is a complex and complicated organ. No two mTBIs are the same and, consequently, no two treatment programs can be identical. We have outlined a comprehensive approach to post-concussion management of the athlete, designed to return him/her not only to sport, but also to school, vocation, and active socialization with family and friends. Realistically, scarcity of financial resources, lack of internet access, and geographical remoteness may interfere with access to a multi-disciplinary team. In these cases, a systematic and thorough clinical evaluation, with repeated monitoring across multiple environments (e.g., academia, work, social, and home) and including psychosocial and cognitive tasks, will ensure that the player has recovered fully before returning to play and life participation.

The athlete’s long-term goals typically target environments and roles that they are expected to resume (academia, work, social, and sport). When the athlete becomes asymptomatic at rest, or presents with chronic symptoms, he or she should be assessed while performing symptom provoking movements and activities, in order to ensure full recovery, or to assess status in recovery. The sports physical therapist should initiate gradual return, with the athlete remaining symptom free, not only to sport activities, but also to social and academic and/or employment related activities. Nonetheless, the investigation of multidisciplinary treatment for post-concussion symptoms is in its infancy. It is imperative for future research to investigate consistent application of methods to obtain quantifiable results that can add evidence to the efficacy of specific assessment and therapeutic techniques for athletes who suffer one or repeated concussion(s).

REFERENCES


ABSTRACT

Most athletic events present potential for abdominal trauma for their participants. The responsibility of the “most medical” professional at the event is to have the knowledge to recognize, treat, and properly manage these injuries. As these injuries are very different in nature from orthopedic injuries, the dangers presented are also very different, and can include outcomes as serious as organ failure and death. Because of these differing risks, many professionals are uneasy about proper treatment, especially on the sidelines. However, with a few key points about mechanism of injury, monitoring changes in vital signs, and careful assessment of presenting symptoms, most abdominal injuries can be properly managed on the sidelines.

Key Words: abdominal trauma, emergency response, herniation, organ damage, rupture

Level of Evidence: 5
INTRODUCTION
Abdominal injuries in athletes can range in severity from abdominal strains to internal bleeding, and even insignificant injuries can prove to be incredibly painful. Therefore, the importance of the sports physical therapist’s knowledge of abdominal injuries is imperative. The most medical professional in the stadium or arena must understand the signs and symptoms, possible risks, as well as the mechanism of injury of many of these common injuries in order to properly treat the athlete, and decide whether “proper treatment” is to hold them out of the game or transport them to emergency care. Abdominal injuries in the athlete are among the most potentially dangerous, and the importance of understanding these injuries cannot be understated.

BACKGROUND AND ANATOMY
The abdomen is a relatively unprotected area; susceptible to trauma such as contusions, lacerations, puncture wounds, and herniations. The abdomen (unlike the thorax) has no bony structural protection and relies solely on soft tissue in the form of the abdominal wall, fascial layers, and skin for protection. (Figure 1). The abdominal cavity houses many of the vital organ systems, which could be injured during sport. (Figure 2) This structural difference in support and protection allows for a wide variety of injuries to occur in both collision and contact sports. The sports physical therapist must be well trained in assessment and management of abdominal injuries as a part of specialty practice.

INJURIES
One of the most common injuries to the abdomen is a blow to the solar plexus, which gives a momentary paralysis of the diaphragm and the sensation of having “the wind knocked out of you.” These injuries can happen from being hit in the stomach with a shoulder, a helmet, or falling onto a hard object such as a ball. Although a relatively insignificant injury, likely to pass without much intervention, it can cause significant distress in the athlete as it is occurring. The athlete will experience substantial pain and acute shortness of breath, which often incites the feeling of panic. The sideline PT’s job in this situation is to recognize the injury and assist the player in calming down and resuming normal breathing.

Hernias are protrusions of the intestines through the abdominal wall, and most often occur through the femoral ring or the inguinal canal. With the femoral ring, the intestines protrude below the inguinal ligament and through the femoral canal, and with the inguinal area, the intestines protrude through the inguinal canal along with the spermatic cord. With either of these types of hernia, the main cause is a sharp increase in abdominal pressure due to a muscle contraction or an applied external pressure. The athlete may or may not present with tenderness or a palpable mass at the site of herniation, but if a hernia is suspected, immediate action is required to
prevent strangulation of the intestine and subsequent tissue necrosis.1

The abdominal muscles are the main support for the abdominal area and therefore are susceptible to multiple types of injuries. The athlete can sustain overuse injuries and strains of the abdominal region due to its functional importance in the maintenance of balance and stability, and the linking of the upper quarter to the lower quarter. This is especially apparent in throwing athletes where abdominal strains are common and frequently cause time loss from sport. These muscular injuries should be treated as any other strain of a muscle would, with active rest, reduction of inflammation and appropriate stretching and strengthening. Minor traumas resulting in mild pain are common but severe contusions to the abdominal musculature are rare. The muscle and abdominal contents are soft and thus able to dissipate the majority of most blunt trauma, so bruising and soreness are the most common symptoms, but underlying injury to soft tissues and organs must be considered.2

Organ damage is potentially the most dangerous abdominal injury seen on the sidelines. It is usually caused by blunt trauma to the abdomen, and fatal internal bleeding or organ failure can result. Obviously if any sort of substantial penetrating injury has occurred to the abdomen, organ damage must be assumed and proper wound care and transportation to medical services must ensue. In spite of this, organ trauma can be deceiving, and only mild tenderness, muscle guarding and abdominal splinting can hide the severity of the trauma. Organs can hemorrhage slowly for days or even weeks before symptoms of systemic dysfunction or organ failure will be displayed. For this reason, all athletes with significant abdominal trauma should have a medical examination even if they show no obvious signs of organ damage.

For example, a direct blow to the full bladder can result in a rupture, but is uncommon because few athletes are able to participate with a fully distended bladder. Symptoms will include hematuria, difficulty with urination and abdominal rigidity. A blow to the lower back can result in a contused or ruptured kidney, which can also cause the athlete to present with hematuria. Muscle guarding, back and flank pain, nausea, vomiting, and even shock are possible with significant trauma to the kidneys. With enough force transferred to the abdominal area, intestinal damage and even bowel perforation can occur. Intestinal symptoms will include tenderness to the area, changes in bowel function or bloating, and systemic symptoms such as temperature or blood pressure changes. Intestinal perforations can be confirmed by CT scan or ultrasound where with fluid or air would be seen external to the intestine.3

Blunt trauma to the high abdomen, especially to the right side, can result in damage to the liver. Liver trauma can be potentially fatal due to its importance in bodily function, size, and potential to hemorrhage. Those with significant liver trauma can present with rapid heart rate, low blood pressure, abdominal pain, nausea, and blood in vomit, feces or urine.4

Lastly, splenic ruptures are a very serious condition, and are the leading cause of death by abdominal trauma in athletics. This can be a concern with any athlete presenting with a systemic illness, like mononucleosis, which causes splenomegaly. Splenic rupture can result in symptoms as serious as internal bleeding and can produce symptoms of shock such as clammy, cool, pale skin and weak rapid pulse. If internal bleeding or pressure from a ruptured spleen is irritating the diaphragm, Kehr’s sign will appear, which gives referred pain to the left shoulder and arm.5

ASSESSMENT

If any of these serious organ injuries is suspected at an athletic event, the “most medical” professional on the premises should step forward to take responsibility for the situation. A few simple assessment techniques for this responsible professional would be rebound tenderness (Figure 3), vital signs, and common sense questions about the athlete’s overall symptoms. To perform the rebound test, press firmly into the abdomen with the pads of your fingers with both hands overlapped and release the pressure quickly. If the athlete complains of significant tenderness after the release of pressure, there is sufficient evidence of organ damage to secure transportation for the athlete for advanced medical treatment. Also, if the player’s vital signs are significantly altered or they complain of serious abdominal or systemic symptoms after trauma to the trunk, there should not be any question about their need for medical evaluation. If the player is unsafe to transport or if medical professionals are
on their way, place the player in a position of comfort and continue to monitor their symptoms, but do not give them any liquids to drink. Furthermore, if shock symptoms or the beginning signs of shock are observed, elevate the player's legs to assist blood flow to the head and heart and manage the subsequent scenario appropriately.6

CONCLUSION

The abdomen is an extraordinarily important, yet unprotected area of the body. In addition to its lack of protective structure, its size, intermediate location on the body, and proportion of the body's area increases its vulnerability to injury. In nearly all athletic events, injury to the abdomen is a potential hazard, and recognizing the signs of serious damage is imperative. Abdominal injuries can be lethal and the severity of any injury should not be underappreciated, however with proper training and knowledge, these injuries can be effectively managed on and off the field.

REFERENCES


Figure 3. The rebound test, note placements of the hands for performance of this test.
ABSTRACT

Purpose/Background: While various techniques have been developed to assess the postural control system, little is known about the relationship between single leg static and functional balance. The purpose of the current study was to determine the relationship between the performance measures of several single leg postural stability tests.

Methods: Forty six recreationally active college students (17 males, 29 females, 21 ± 3 yrs, 173 ± 10 cm) performed six single leg tests in a counterbalanced order: 1) Firm Surface-Eyes Open, 2) Firm Surface-Eyes Closed, 3) Multiaxial Surface-Eyes Open, 4) Multiaxial Surface-Eyes Closed, 5) Star Excursion Balance Test (posterior medial reach), 6) Single leg Hop-Stabilization Test. Bivariate correlations were conducted between the six outcome variables.

Results: Mild to moderate correlations existed between the static tests. No significant correlations existed involving either of the functional tests.

Conclusions: The results indicate that while performance of static balance tasks are mildly to moderately related, they appear to be unrelated to functional reaching or hopping movements, supporting the utilization of a battery of tests to determine overall postural control performance.

Level of Evidence: 3b
INTRODUCTION
Subconscious maintenance of postural stability unconsciously underlies all movements, from planned skill executions to reflexive responses following unexpected perturbations. In works that have considered postural stability from an orthopedic perspective, a wide variety of tests, conditions, and variables have been utilized to determine and describe the construct of postural stability. Although several authors have proposed different approaches to categorizing many of the tests, no single classification system has been universally adopted. While double leg stance analysis dominates the postural control literature, measuring single leg postural stability is more applicable in clinical and research sports medicine settings for a variety of reasons.

Sports and physical activities require periods of time where an individual must rely on a single leg base of support, therefore, the use of single leg tests to measure postural stability in a clinical or research sports medicine settings is both logical and warranted. Relying on a single leg base of support requires the postural control system to reorganize the total body center of mass over a narrow base of support. In addition to the functional applicability, assessing single leg postural stability reduces the number of peripheral sensory sources and muscle strategies that may serve to compensate for peripheral deficiencies. In a clinical setting, the convenience of making bilateral comparisons or examining bilateral differences in cases of unilateral orthopedic injury further contributes to the applicability of single leg tests to determine postural control ability.

Current examination systems and rehabilitation programs used with patients who have experienced a lower extremity injury often stress static (fixed based of support) stance proficiency as a prerequisite for more dynamic and functional exercises. While this suggestion makes intuitive sense, the degree to which static stance proficiency relates to dynamic and functional postural control performance remains largely undocumented. Research examining both static and/or dynamic balance ability independently is widely available, yet little research has directly examined the relationship between static, dynamic and functional balance particularly for single leg balance. Drawing consensus across the studies considering the relationship between various modes of single leg postural control assessment is difficult because of the varying population characteristics, the different tests used and the varied results. The relationship between static single leg balance with the star excursion balance test (SEBT) and stepping/stabilization on foam has been studied the most. While Clark and colleagues reported a significant relationship between a static test and the SEBT, Nakagawa and Hoffman failed to reveal any relationship. Likewise, Hrysomallis and colleagues demonstrated a significant relationship between a static test and stepping/stabilization test while Nakagawa and Hoffman failed to reveal any relationship. With regards to the relationship between static test performance and functional activities, one study examining single leg hop for distance demonstrated that weak to moderate relationships (r = .37 to .63) with several single leg stance tests, while an earlier study failed to reveal any relationship between single leg stance stability measures measured using a forceplate and a battery of walking and coordination tasks.

Thus, based on the above results, there is clearly a need for further research examining the relationships between various modes of single leg postural control assessment so clinicians have an objective basis for selecting a particular test or training task in the evaluative and rehabilitation stages of orthopedic injury. Establishing whether relationships exist between static stance and functional postural control is the first step in providing evidence regarding whether the different testing modes may be assessing unique aspects of the construct of postural stability. Therefore, the purpose of this investigation was to determine the relationship between performances of several single leg postural stability tests in a sample of recreationally active college students.

METHODS
Subjects
Forty-six recreationally active, healthy, college students (17 males, 29 females, age = 21±3 years, height = 173±10 cm, mass = 68±12 kg) participated in this study. All subjects were free of any lower extremity orthopedic related injuries or neurologic disorders and previous history of head injury or balance disorders as indicated by a medical history questionnaire. Prior to
participation, informed consent from each participant was acquired using a local institutional review board approved consent document.

**Design**

Each subject attended one testing session that lasted approximately 25 minutes in duration. Within the testing session, each subject performed a battery of six single leg postural stability tests: 1) Firm Surface-Eyes Open (FIEO), 2) Firm Surface-Eyes Closed (FIEC), 3) Multiaxial Surface-Eyes Open (MAEO), 4) Multiaxial Surface-Eyes Closed (MAEC), 5) Posterior-medial reach of the Star Excursion Balance Test (SEBT), 6) Single Leg Hop-Stabilization test (SLHS). All testing procedures were conducted using the dominant limb of each participant. Dominant limb was defined as the preferred leg to use to kick a ball. Additionally, the order in which tests were administered was unique for each participant by randomly assigning a particular order from all possible testing orders.

**Firm and Multiaxial Surface Testing**

The eyes open and eyes closed firm surface testing was conducted using a Bertec 4060-NC Force Plate and AM-6700 amplifier (Bertec Co., Columbus, OH) sampled at 100Hz using a LabVIEW (National Instruments, Austin, TX) based acquisition program. A similar single leg testing protocol previously developed and demonstrated to be reliable by Goldie et al. was used. Subjects were instructed to stand as motionless as possible, maintain their hands on the iliac crests and their non-dominant limb in 30° of hip and knee flexion (Figure 1). During each trial, subjects were encouraged, if it became necessary, to touchdown on the force platform with their non-dominant limb. For each testing condition, subjects performed one seven second practice trial followed by three identical seven second test trials. The authors own pilot work has supported the reliability for this trial duration as being compatible with 15s trials, but with the advantage of a reduced number of touch downs. Thirty-second rest periods were allotted between trials by allowing the subject to touchdown on their contralateral limb. Similar stance and trial procedures as the firm surface testing were used for the multiaxial surface testing (Figure 2). A commercially available multiaxial surface (Gordons Balance Board, Gordons Research and Development, Inc, Pinckneyville, IL) was placed directly on the force plate. The stability of the multiaxial surface is adjustable by interchanging the column support, and/or column length. For the purposes of this investigation, a moderate stability level (green column, first hole length) was used based on pilot work with 10 additional subjects. Pilot work established the cross correlational coefficients (zero phase lag) between multiaxial platform tilt and center of pressure excursion to be .91±.06 and .80±.17 for anterior-posterior and medial-lateral, respectively, supporting the usage of a center of pressure derived measure to reflect multiaxial surface performance.

In the event that three or more compensatory events occurred during the firm and multiaxial surface testing, subjects were given one re-test trial. Compensatory events were defined according to the Balance Error Scoring System (BESS). In short, the BESS was developed as...
a portable and objective method of assessing static postural stability without requiring complex or expensive instrumentation. The tester scores balance performance by counting the number of errors committed during a trial. The BESS errors considered compensatory events for the current study included lifting the hands off the iliac crests, opening the eyes during eyes closed trials, stepping or stumbling, moving hip into more than 30° of flexion or abduction, and lifting forefoot or heel.

Custom software was written to conduct data reduction procedures. This included smoothing the force and moment data obtained from the force plate (10 Hz cutoff) and calculating the average center of pressure velocity during the middle 5 seconds of data.

Star Excursion Balance Test (SEBT)

The original SEBT consists of a series of 8 postural stability tests that incorporates single-leg stance of one leg with a maximum targeted reach with the contralateral leg. The subject stands at the center of a grid pattern laid on the floor consisting of 8 lines extending at 45° increments from the center of the grid in a star pattern. For each respective reach, the distance the subject is able to extend the free leg and tap down on the respective grid line while maintaining a single leg stance is marked and measured from the center of the grid. The results of factor analysis revealed the posterior-medial reach to be most representative of performance in all eight directions. Thus, in the current investigation, the average of the three posterior-medial reach trials was normalized to body height and was used as the measure of SEBT performance (Figure 3). Because subjects were required to maintain their hands on their iliac crests during all other tests comprising the investigation, a modification to the original SEBT description was made to include the requirement of the hands remaining on the iliac crests during each reach. A previous study found that following a practice session (both participants and testers), the intratester reliability of the SEBT has been reported to range between .82 and .96, while intertester reliability was reported to range between .81 and .93. Additionally, based on the documentation concerning multiple exposure effects in the posterior medial reach direction by Hertel et al, four practice trials were given to the subjects prior to the test trials.

Single leg Hop-Stabilization Test (SLHS)

The Single Leg Hop-Stabilization Test requires the subject to sequentially single leg hop through a ten point floor pattern using one leg while maintaining the hands on the iliac crests (Figure 4). The dimensions of the floor pattern are modified according to the height of each subject. Subjects are instructed to begin on the start mark with their dominant foot covering the tape mark, facing forward, with the hands on the iliac crests. They are required to hop to the first tape mark, and upon landing, maintain single leg balance with their hands on their iliac crests for five seconds. At the conclusion of five seconds, the subject is then instructed to hop to the next successive tape mark, repeating the procedure through all ten points of the floor pattern. Performance during the test is determined using separate criteria for the two phases of the test (landing and balance). The landing phase includes landing on the tape mark and establishing body control. The balance phase
analyses between the six postural stability tests are presented in Table 3. In general, with the exception of the relationship between the FIEC and MAEO (r = .267, p = .073), significant mild to moderate (r = .371 to .624) relationships were revealed between firm and multiaxial surfaces. No significant relationships (r = .006 to .268) were revealed between the firm and multiaxial surfaces and the SEBT or SLHS.

DISCUSSION
The major purpose of this investigation was to determine if relationships existed between performances on several single leg postural tests. Significant mild to moderate strength correlations were revealed between performance of the firm and multiaxial surface tests. The most important result was that no significant relationships were revealed between static tests and either of the more dynamic (SEBT and SLHS) tests. These results suggest that while performance on the static stabilization tasks (firm and multiaxial surfaces) appears to be interrelated, proficient performance does not relate to voluntary reaching and hopping movements. Clinically, this raises a question concerning sole use of many traditionally

encompasses the subsequent 5 seconds after body control is established during which the subject maintains single leg balance before the next jump is executed. Criteria for error in landing and balance are included in Table 1. Intertester reliability (standard error of measurement) was reported to be .92 (.57) for the landing scores and .70 (.55) for the balancing scores. Prior to the scored trials, in accordance with the multiple exposure effects previously documented, subjects were given ample opportunity to practice the hop-stabilization sequences to become familiar with the hop distances and directions as well as transitioning into static stance.

Data Analysis
Consistent with the purpose of the investigation, Pearson correlational analyses were conducted between the dependent variables describing performance of the single-leg postural stability tests. The level of significance was preset at .05 for all analyses.

RESULTS
Descriptive statistics for the dependent variables are presented in Table 2. Results of the correlational analyses between the six postural stability tests are presented in Table 3. In general, with the exception of the relationship between the FIEC and MAEO (r = .267, p = .073), significant mild to moderate (r = .371 to .624) relationships were revealed between firm and multiaxial surfaces. No significant relationships (r = .006 to .268) were revealed between the firm and multiaxial surfaces and the SEBT or SLHS.
utilized postural control tests (i.e. stationary single leg stance on a force plate) to determining the postural control requirements associated with activities of daily living and physical activity. Rather, the results of this investigation support the notion that a battery of tests, including more functional tests that involved movement, be used to fully evaluate an individual's postural control abilities.

It is important to recognize the characteristics and limitations associated with the research design of this investigation. Correlational investigations, such as the current work, do not offer information regarding cause and effect but rather the presence and magnitude of relationships existing between various dependent variables. Thus, the results of the current investigation must be prudently considered to suggest that static stabilization task (firm and multiaxial) proficiency does not statistically predict either aptitude or inability to perform the voluntary movement tasks (SEBT and SLHS). Further research using an experimental design with static and dynamic postural control training methods is needed to more completely understand the degree to which static stabilization performance may contribute to dynamic and functional balance abilities.

The current study was unique in considering two static stabilization tasks on two different surfaces under both eyes open and closed conditions. With the exception of the relationship between the firm surface-eyes closed and multiaxial surface-eyes open, the only significant relationships revealed in the current study involved these four tests. This was not unexpected as all four tests had a similar objective of directing conscious attention solely upon standing as motionless as possible. Interestingly, in contrast to the moderate strength relationship revealed between performances on the two surfaces under eyes closed, the relationship under eyes open was weak. One possible immediate statisti-

Table 1. Single leg hop-stabilization test error scoring system.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landing</td>
<td>Not covering tape mark</td>
</tr>
<tr>
<td></td>
<td>Stumbling on landing</td>
</tr>
<tr>
<td></td>
<td>Foot not facing forward with 10 degrees of rotation</td>
</tr>
<tr>
<td></td>
<td>Hands off hips</td>
</tr>
<tr>
<td>Balance</td>
<td>Touching down with nondominant limb</td>
</tr>
<tr>
<td></td>
<td>Nondominant limb touching dominant limb</td>
</tr>
<tr>
<td></td>
<td>Nondominant limb moving into excessive flexion, extension or abduction</td>
</tr>
<tr>
<td></td>
<td>Hands off hips</td>
</tr>
</tbody>
</table>
cal interpretation of this result may be attributable to the small range of scores for the firm surface-eyes open test. However, because the strongest relationship was demonstrated between the two tests with the smallest range of scores, the eyes open and closed tests on the firm surface, thus, this potential explanation is not the only explanation to be considered.

A second possible explanation for the differences in relationships between the firm and multiaxial surfaces under similar visual conditions may be related to the challenges imposed upon the sensory and motor components of postural control system by the surface and visual conditions. Compared to double leg stance, single leg stance is associated with decreased stability.

### Table 2. Means and standard deviations (SD) for the postural tasks.

<table>
<thead>
<tr>
<th>Test</th>
<th>Mean±SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firm surface-eyes open</td>
<td>4.20±1.22 cm/s</td>
</tr>
<tr>
<td>Firm surface-eyes closed</td>
<td>10.84±4.06 cm/s</td>
</tr>
<tr>
<td>Multiaxial surface-eyes open</td>
<td>13.31±5.42 cm/s</td>
</tr>
<tr>
<td>Multiaxial surface-eyes closed</td>
<td>19.82±9.18 cm/s</td>
</tr>
<tr>
<td>STAR excursion test (posterior-medial)</td>
<td>38.6±8.8%BH</td>
</tr>
<tr>
<td>Single leg hop stabilize-Land errors</td>
<td>3.6±2.0</td>
</tr>
<tr>
<td>Single leg hop stabilize-Balance errors</td>
<td>3.7±1.7</td>
</tr>
<tr>
<td>BH=Body height</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3. Correlational coefficients between the postural tasks.

<table>
<thead>
<tr>
<th></th>
<th>FIEO</th>
<th>FIEC</th>
<th>MAEO</th>
<th>MAEC</th>
<th>STAR</th>
<th>SLHS-Land</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIEC</td>
<td>r=.624</td>
<td>p&lt;.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAEO</td>
<td>r=.371</td>
<td>p=.011</td>
<td>r=.267</td>
<td>p=.073</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAEC</td>
<td>r=.480</td>
<td>p&lt;.001</td>
<td>r=.561</td>
<td>r=.540</td>
<td>p&lt;.001</td>
<td></td>
</tr>
<tr>
<td>STAR</td>
<td>r=.114</td>
<td>p=.449</td>
<td>r=.086</td>
<td>r=.006</td>
<td>r=.179</td>
<td>p=.234</td>
</tr>
<tr>
<td>SLHS-Land</td>
<td>r=.260</td>
<td>p=.081</td>
<td>r=.188</td>
<td>r=.111</td>
<td>r=.065</td>
<td>r=.217</td>
</tr>
<tr>
<td>SLHS-Balance</td>
<td>r=.089</td>
<td>p=.847</td>
<td>r=.029</td>
<td>r=.268</td>
<td>r=.173</td>
<td>r=.174</td>
</tr>
</tbody>
</table>

FIEO= Firm surface-eyes open
FIEC= Firm surface-eyes closed
MAEO= Multiaxial surface-eyes open
MAEC= Multiaxial surface-eyes closed
STAR= Star excursion balance test posterior-medial reach
SLHS-Land= Single leg hop stabilize test-land errors
SLHS-Balance= Single leg hop stabilize test-balance errors
secondary to the narrower base of support, which seems to increase the reliance on visual information, as well as increase the amount of corrective action required at the ankle, knee, hip and trunk.\textsuperscript{17} Standing on an unstable surface has been suggested to require faster stabilization mechanisms that originate from proprioceptive input,\textsuperscript{18,19} which in turn, increases ankle and trunk corrective action necessary to maintain equilibrium.\textsuperscript{17} Thus, in the current study, performance not being correlated between the surfaces with the eyes open may indicate that the challenges imposed may be challenging the postural control system differently or that ability of subjects to adapt to the different challenges is inconsistent. Further research is needed to better clarify how different surfaces, coupled with changes in visual conditions, affects the postural control system.

In addition to the aforementioned studies in the introduction considering the relationships between various single leg balance tests in young adults, Ekdahl et al\textsuperscript{5} considered the relationship between the time required to walk 30m and a coordination task (concomitant arm and contralateral leg flexion occurring within 15s) with traditional forceplate measures of single leg stability (center of pressure path, velocity and area) in 152 healthy participants (78 males, 74 females, aged 20-64 years). Similar to the current investigation, the authors failed to reveal significant relationships between the voluntary movement and stability tasks. Similarly, Lindmark et al\textsuperscript{20} examined the relationship between performance of a battery of functional tasks and stability during single leg eyes-open stance (center of pressure excursion velocity) in a population of 100 menopausal women. The results of their investigation failed to reveal any significant relationships with the exception of a weak relationship involving the figure eight walk test (r = .25). Coupled with the results of studies described in the introduction to this paper, the current results of static stabilization performances not relating to the two more dynamic test performances adds further support to the notion that the predictive value of static balance performance to dynamic balance is negligible.

Qualitative analysis of the postural stability tasks used in the current investigation can offer additional insight into the results attained. Close inspection of the demands imposed by the voluntary movement tests suggests that both tests (SEBT and SLHS) required some degree of proficient single leg stabilization for successful completion. The external constraints imposed by all tests in this investigation included the hands remaining on the iliac crests to decrease the amount of compensatory motion arising from upper limb movement. Specifically, during the completion of the entire SEBT participants had to remain in single leg stance equilibrium while the contralateral extremity was extended in a posterior-medial direction. While the quantity of corrective action required to remain in equilibrium was not a direct component of the scoring, it logically follows that being able to control the body's center of mass (COM) over a fixed base of support would have been a prerequisite skill. Likewise, the end of the SLHS landing phase required the participants to control movement of their body's COM following ground contact over a fixed single leg base of support. This was then followed by a brief stance period in which stance was maintained with minimal corrective action. Intuitively, a fixed base of support control would also be a logical prerequisite for optimal SLHS performance. Despite the attractiveness of this theory, no significant relationships between the tasks were revealed. One explanation for the lack of significant relationships revealed could be related to the concentration being focused solely on stabilization during the firm and multiaxial surface tests, whereas during the SEBT concentration was on reaching and during the SLHS concentration was divided between stabilization and anticipating the next hop.

An additional explanation for the lack of significant relationships between the two types of tasks could be that the limiting factor in the voluntary tasks did not reside in the ability to stabilize, but rather in other component(s) of the postural control system. Intuitively, both the SEBT and SLHS appear to require a heightened level of coordination about the ankle, knee, and hip joints. Factoring into the coordination patterns selected is the amount of muscle strength and endurance, as well as available range of motion about each of the joints.\textsuperscript{3} Again, it is recommended that future research consider using true experimental designs to further explore the factors contributing to proficient performance of the voluntary movement tasks.
It is important to recognize some of the limitations associated with this study. First, this study only used healthy subjects aged 18 to 30 years old. This decision was made to reduce any potentially confounding factors (musculoskeletal, neurologic or vestibular pathologies) on the relationships revealed. The degree to which these results would apply to persons with orthopedic pathology is unknown. In addition, the resulting sample involved a disparity in the number of men and women participants. With largely only firm surface stance being considered, the literature is inconsistent regarding whether there are sex differences in balance performance. While some studies suggest women have better balance than men, other studies have revealed better balance in men. Complicating the question of whether sex differences exist in balance performance are the differences in anthropometric characteristics (i.e., height, weight, body mass index, etc.) and physical activity history. For the current investigation, even if sex differences in balance performance exist, there does not appear to be any evidence in the literature to suggest an interaction between sex and the relationship between various modes of single leg balance assessment. Nonetheless, this should be regarded as a possible limitation and an area for future research. Finally, we did not formally conduct a reliability study specific to the current investigation. The decision to forego a reliability study was made because of the experience the investigators had with developing several of the tests and methods used in the current investigation, coupled with the extensive protocol rehearsal that was conducted in preparation for the current investigation. Thus, while it is unlikely that the reliability of the testing conducted should deviate from previously published reports, because reliability was not formally document as part of the current investigation it should be recognized as a limitation.

CONCLUSION

Because a strong correlation between the static stabilization tasks and the voluntary movement tasks was not evident, it can be deduced that these types of tasks measure different constructs, each taxing different postural control mechanisms. Until the underlying differences in the tasks are tested and identified, this investigation can be considered to provide a rationale for assessing postural control in young, physically active individuals through use of a battery of tasks. It is suggested that clinicians consider evaluating and exercising the postural control system through both traditional single leg stance activities as well as voluntary, more functional movements. Further research is needed to identify which aspect of the postural control system each task optimally targets and assesses, as well as the limitations to performance of the various tasks.

REFERENCES


ABSTRACT

Purpose: The purpose of this study was to examine the relationships between isotonic ankle plantar flexor endurance (PFE), foot pronation as measured by navicular drop, and exercise-related leg pain (ERLP).

Background: Exercise-related leg pain is a common occurrence in competitive and recreational runners. The identification of factors contributing to the development of ERLP may help guide methods for the prevention and management of overuse injuries.

Methods: Seventy-seven (44 males, 33 females) competitive runners from five collegiate cross-country (XC) teams consented to participate in the study. Isotonic ankle PFE and foot pronation were measured using the standing heel-rise and navicular drop (ND) tests, respectively. Demographic information, anthropometric measurements, and ERLP history were also recorded. Subjects were then prospectively tracked for occurrence of ERLP during the 2009 intercollegiate cross-country season. Multivariate logistic regression analysis was used to examine the relationships between isotonic ankle joint PFE and ND and the occurrence of ERLP.

Results: While no significant differences were identified for isotonic ankle PFE between groups of collegiate XC runners with and without ERLP, runners with a ND >10 mm were almost 7 times (OR=6.6, 95% CI=1.2-38.0) more likely to incur medial ERLP than runners with ND <10 mm. Runners with a history of ERLP in the month previous to the start of the XC season were 12 times (OR=12.3, 95% CI=3.1-48.9) more likely to develop an in-season occurrence of ERLP.

Conclusion: While PFE did not appear to be a risk factor in the development of ERLP in this group of collegiate XC runners, those with a ND greater than 10 mm may be at greater odds of incurring medial ERLP.

Level of Evidence 2b.

Key Words: exercise related leg pain, medial tibial stress syndrome, running, shin splints

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INTRODUCTION

A 2008 National Sporting Goods Association (NSGA) study estimated from a sample of 10,000 households that 35.9 million people participate in running/jogging more than five times a year. This estimate was an 18.2% increase from the 2007 estimates for running/jogging participants aged 7 years or older. Running USA reported that an estimated 507,000 runners finished a marathon in 2010, an 8.6% increase from 2009 and a 255% increase from 1980. Women are largely responsible for the growth in marathon running, comprising 41% of participants in 2010, as compared to 10% participation in 1980. Growth in running participation has also led to an increased interest in running related injuries. Authors who have studied the incidence of overuse leg injuries in runners report injuries occurring between 14.6% and 38.8% of the subjects. Researchers who have examined overuse leg injuries in collegiate cross-country runners have reported incidence estimates of such injuries occurring in 26.3% and 38.8% of athletes. In a survey of 844 recreational runners, the proportion of injuries to the lower leg was second only to the knee, with tibial stress syndrome being the most commonly diagnosed injury overall.

Exercise-related leg pain (ERLP) and shin splints are non-specific terms used to describe lower leg injuries resulting from cumulative, microtraumatic events. ERLP is described as a regional complex of injuries causing “pain in the anterior, medial, posterior, or lateral leg associated with exercise.” Burne et al further distinguished the location of ERLP by excluding subjects with anterior, posterior and lateral leg pain in their study on exertional medial tibial pain (EMTP). Common medical diagnoses associated with ERLP include tendinopathy, stress fracture, medial tibial stress syndrome (MTSS), chronic exertional compartment syndrome, periostitis, nerve entrapment, and vascular insufficiency.

Risk factors for overuse injuries are often classified as intrinsic or extrinsic, and modifiable or non-modifiable. Intrinsic risk factors are characteristics such as age, gender, and injury history while extrinsic factors include training surface, training volume, and equipment. Modifiable factors include strength, flexibility and training variables that can be altered with direct intervention, while non-modifiable factors include age and gender. Meeuwisse et al proposed a model emphasizing the interaction of both internal and external factors in creating a situation of susceptibility for the athlete, with injury occurring in the presence of an inciting event or events. This model also reflects how exposure to inciting events can result in adaptation of modifiable traits, resulting in an increased or decreased risk of injury. Prevention of injury occurs by addressing modifiable traits such as strength, flexibility, and balance through exercise or minimizing exposure to inciting events. Research examining risk factors for sports injury should focus on modifiable factors that can be reliably measured.

Excessive pronation has been frequently studied as a potential risk factor in the development of leg injuries in runners. Previous studies using navicular drop (ND) as a measure of pronation have reported significant relationships to ERLP and MTSS. Other studies did not find a significant relationship between ND and medial leg pain creating a knowledge-knowledge conflict. Modifying pronation with exercise and orthotic prescription is often included in the management of overuse lower extremity injuries. Pronation as measured by two-dimensional video analysis has been shown to decrease during treadmill running following eight weeks of isokinetic inversion and eversion strength training. Foot orthotics have been shown to alter rearfoot motion - a component of pronation – supporting their use in decreasing the demand on soft tissue structures and reducing injury.

The inability of the leg muscles to attenuate ground reaction forces has been suggested as a possible mechanism leading to ERLP. Madeley et al examined the isotonic endurance of ankle plantar flexors (PFE) in 30 athletes with MTSS and 30 matched controls. They found a significant difference in ankle PFE in the MTSS group when compared to the matched controls. As a retrospective, case-control study was used, a temporal relationship between PFE and MTSS could not be established, but their results warrant further investigation.

Successful prevention of sports injuries requires the prompt and empirical treatment of identifiable and modifiable risk factors. Understanding the relationship between ankle PFE, pronation and the development of ERLP may assist in the prevention and
treatment of injury in runners. The purpose of this study was to measure isotonic ankle PFE and pronation, and then prospectively determine their relationship to in-season occurrence of ERLP in collegiate cross-country runners. Gender, height, weight, body mass index (BMI), orthotic use, and previous injury were also recorded as prior studies have reported that these factors have a significant influence on injury occurrence.\textsuperscript{7,14,24,40,41} The authors expected that decreased PFE or increased pronation would increase the risk of developing ERLP among a cohort of collegiate cross-country runners during an intercollegiate XC season.

**METHODS**

**Subjects and Setting**

This study used a prospective, cohort design. An a priori power analysis was performed using an alpha level of 0.05, a power of 0.80, an estimate of 40\% of subjects exposed to navicular drop > 10 mm, and a relative risk of 2.0. It was estimated that a sample size of 262 subjects was needed to detect a statistically significant association between ND and ERLP.

Seven collegiate institutions with an estimated total of 150 cross-country athletes were invited to participate in this study. Subjects from four universities in Missouri and one college in Illinois were recruited prior to the 2009 cross-country season. An initial meeting was scheduled with coaches and athletes at each institution to describe the study’s purpose and design and obtain informed consent. Researchers then met with those subjects consenting to participate to describe the measurement process and commence data collection. To be included in the study, subjects had to be free of injury at the beginning of the fall season, as defined by the ability to participate fully in team-prescribed practice and competitive activities. Subjects were excluded based on a surgical history related to the lower extremity, or if the runner was unable to participate fully in running activities due to injury. The final study cohort consisted of 44 male and 33 female collegiate cross-country runners. The study was approved by the Rocky Mountain University of Health Professions Institutional Review Board and the Saint Louis University Institutional Review Board.

**Data Collection**

**Anthropometric Measures**

Baseline anthropometrics were measured for each subject; height was measured using a cloth tape adhered to a wall and weight was measured using an electronic scale. Body mass index (BMI) was calculated using the height and weight measure for each subject.

**Navicular drop**

Navicular drop (ND), defined as the difference between the height of the navicular tuberosity in subtalar joint neutral and the height of the navicular tuberosity in relaxed stance, was measured bilaterally as described by Brody\textsuperscript{42} and has been considered a reliable (ICC = 0.78-0.83) and valid measure of foot pronation.\textsuperscript{43,44} With the subject standing barefoot, the navicular tuberosities were palpated and marked with a felt-tipped pen. Subjects were then asked to stand on the leg being tested with the opposite knee flexed and the hip maintained in neutral. The examiner palpated the medial and lateral prominence of the talus with the thumb and index finger during pronation and supination of the foot. The examiner placed their opposite hand on the lower leg to cue the subject and guide internal and external lower leg rotation. Subtalar joint neutral (STJN) was determined when the talar prominences were congruent medially and laterally. The subject was instructed to hold the STJN position while a ruler was placed alongside the medial aspect of the foot and the navicular tuberosity position was noted. The subject then assumed relaxed standing and the difference between navicular tuberosity positions on the ruler was recorded to the nearest millimeter. The ND test was repeated on the opposite limb, measured and recorded to the nearest millimeter.

**Plantar flexor endurance**

Plantar flexor endurance (PFE) was measured using the standing heel-rise test with slight modification based on differences between previous studies and available resources.\textsuperscript{20,45-48} The standing heel-rise test measures endurance of the plantar flexor muscle group by determining the number of repetitions performed at a rate of 1 heel-rise every two seconds. With the subject standing barefoot and the knee and lower leg fully exposed, the subject was positioned arms length from a wall as determined by placing their hands at shoulder level, elbows fully extended,
forearms pronated, wrists in neutral, fingers fully extended and only their finger tips touching the wall. The subject assumed single leg stance and was asked to perform a single heel rise. During this time the examiner ensured the subject could maintain balance without altering position, and placed two parallel uprights so that the dorsal aspect of the foot contacted a 0.5 mm piece of nylon string just distal to the anterior tibia. The subject was instructed to use their fingertips for balance while keeping the upper extremities in the starting test position. The subject was advised to keep the knee fully extended during testing and to contact the string with each heel-rise at a rate of one heel-rise every two seconds as determined by a metronome set at a cadence of 60 beats per minutes. The number of heel-rise repetitions was recorded by the tester and the subject was allowed to rest for 60 seconds before testing the opposite leg. A value of 25 repetitions is considered normal for males and females based on previous work aimed at determining a reference standard. The current study grouped subjects categorically based on a normal (≥25 heel-rise repetitions) or below normal (<25 heel-rise repetitions) PFE test result.

A pilot study to determine the intratester reliability of the PFE test was performed prior to data collection. Twenty-six subjects were recruited from the general student population at a participating university and measured on two separate occasions using the dominant leg. The intraclass correlation coefficient (ICC 3,1) and 95% confidence interval reliability values for the PFE test was 0.75 (0.52, 0.88; p<0.0001). Ross et al measured test-retest reliability of the PFE test and reported an intraclass correlation coefficient of 0.96. Although intratester reliability of the ND test was not assessed in this study, the researcher (MFR) who performed the ND measurement in the main cohort study, previously conducted a reliability study and reported intraclass correlation coefficient (ICC 3,1) values for right ND (ICC = 0.90), left ND (ICC = 0.78) and combined ND (ICC = 0.84) measures in a prior study. Using the reliability data for the ND test the standard error of measurement (SEM) was calculated to be 1.2 mm.

**Preseason Questionnaire**

Subjects were asked to complete a 10 minute, preseason questionnaire that asked them to report their gender, age, ERLP history for the previous month and year, and current use of foot orthoses.

**Exercise-related leg pain**

Exercise-related leg pain (ERLP) is operationally defined as pain located in the anterior, medial, posterior, or lateral leg not associated with a traumatic injury. Nirschl pain phase scores and visual analogue scores (VAS) were recorded in subjects having a history of ERLP and in-season occurrence of ERLP. The Nirschl pain phase scale is a seven-phase scale for overuse injuries ranging from transient pain that resolves within 24 hours to consistent pain that disrupts sleep and intensifies with activity. Subjects with a Nirschl pain phase score of 4 or greater – described as pain resulting in alteration of performance – were subcategorized as having interfering ERLP. The visual analog scale is an 11 point scale with zero equal to no pain and 10 equal to the worst imaginable pain. Subjects were also subcategorized into medial, lateral or posterior groups based on the location of their ERLP.

At the end of the competitive cross-country season, the subjects received an email with a web address and request to complete an online postseason questionnaire. Subjects completing the survey were assigned to one of two groups based on the occurrence of ERLP during the 2009 cross-country season. Location and severity of pain were recorded and pain severity was quantified using Nirschl pain phase scores and VAS ratings as in the preseason questionnaire.

**Data Analysis**

Mean differences between subjects with and without in-season occurrence of ERLP were determined using independent, 2-tailed t-tests for continuous variables (ND, PFE, BMI, age). Crude odds ratios with 95% confidence intervals were initially calculated for ND (>10/≤10 mm), PFE (<25/≥25 repetitions), and other factors (prior ERLP injury, gender), and in-season occurrence of ERLP or in-season occurrence of
medial ERLP. Multivariate logistic regression analysis was used to examine relationships between all measured variables and potential confounders and the in-season occurrence of ERLP and in-season occurrence of medial ERLP. All statistical tests were set at the 0.05 level of significance. All data were recorded and analyzed using SPSS statistical software (version 18.0, Chicago, IL).

RESULTS

While 77 (44 males, 33 females) of 100 (56 males, 44 females) rostered cross-country athletes from four universities and one college consented to participate in this study prior to the 2009 cross-country season, only 59 (31 males, 28 females) of the original subjects completed the end of season questionnaire. The eighteen subjects (13 males, 5 females) who failed to complete the end of season questionnaire were not included in the final data analysis.

There were no significant differences in descriptive categorical variables between the 18 subjects who dropped out and the 59 subjects completing the study (TABLE 1). Subjects denying a history of ERLP in the previous month (29.4%) or year (28.6%) had a tendency that approached statistical significance to drop out compared to subjects with a history of ERLP in the previous month (11.5%, p=0.08) or year (21.4%, p=0.51), respectively. The tendency to drop out was not different in subjects denying a history of ERLP in the last year (28.6%) compared to subjects with a previous year history of ERLP (21.4%, p=0.51).

Gender also approached significance with males nearly twice as likely to drop out (29.5%) than females (15.2%, p=0.14). There were no significant differences for continuous independent variables (ND, PFE, Age, and BMI) between study participants and those who did not complete the study.

The overall in-season occurrence of ERLP was 44.1% (n=26), with an equal number of male and female subjects reporting ERLP during the season. There were no significant differences in gender, age, or BMI between those with and without previous history of ERLP or in-season occurrence of ERLP. BMI < or > 18.5 kg/m² and gender were not significantly different between subjects who did or did not experience ERLP or medial ERLP (TABLE 2) during the season.

A greater percentage of subjects with a history of ERLP in the month prior to the study localized their pain to the medial leg, but location was not significant for previous month history of ERLP or in-season occurrence of ERLP. On average, subjects (N=59) performed 26.6 ± 11.5 heel-rise repetitions on the right and 22.9 ± 8.5 heel-rise repetitions on the left during the PFE test (TABLE 3). There was no difference between groups based on the occurrence of in-season ERLP for mean PFE (TABLE 3) or for those scoring <25 repetitions on the PFE test (TABLE 2) regardless of pain location. Mean PFE (TABLE 3) or performance of <25 repetitions on the PFE test (TABLE 2) also did not differ between groups based on the in-season occurrence of medial ERLP. Females were over 3 times more likely than males to perform less than 25 repetitions during PFE testing (p=0.045).

Means and standard deviations for all subjects (N=59) are provided for right ND (8.5±4.1) and left ND (8.7±4.3) measures in TABLE 3. A comparison of subjects by in-season occurrence of ERLP did not differ significantly for mean ND (TABLE 3) or ND >10 mm (TABLE 2). No significant differences were found between groups for mean PFE (TABLE 3) or performance of <25 repetitions on the PFE test (TABLE 2) regardless of pain location.
<table>
<thead>
<tr>
<th>Factor (category)</th>
<th>ERLP</th>
<th>Medial ERLP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>(%)</td>
</tr>
<tr>
<td><strong>BMI</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 18.5 (underweight)</td>
<td>8</td>
<td>(62.5)</td>
</tr>
<tr>
<td>18.5-24.9 (normal)</td>
<td>51</td>
<td>(41.2)</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>28</td>
<td>(46.4)</td>
</tr>
<tr>
<td>Male</td>
<td>31</td>
<td>(41.9)</td>
</tr>
<tr>
<td><strong>ERLP History (year)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>44</td>
<td>(56.8)</td>
</tr>
<tr>
<td>No</td>
<td>15</td>
<td>(0.07)</td>
</tr>
<tr>
<td><strong>ERLP History (month)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>23</td>
<td>(73.9)</td>
</tr>
<tr>
<td>No</td>
<td>36</td>
<td>(0.3)</td>
</tr>
<tr>
<td><strong>Right ND (mm)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 10 (hyperpronation)</td>
<td>19</td>
<td>(42.1)</td>
</tr>
<tr>
<td>≤ 10</td>
<td>40</td>
<td>(45.0)</td>
</tr>
<tr>
<td><strong>Left ND (mm)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 10 (hyperpronation)</td>
<td>24</td>
<td>(45.8)</td>
</tr>
<tr>
<td>≤ 10</td>
<td>35</td>
<td>(42.9)</td>
</tr>
<tr>
<td><strong>Right or Left ND (mm)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 10 (hyperpronation)</td>
<td>26</td>
<td>(42.3)</td>
</tr>
<tr>
<td>≤ 10</td>
<td>33</td>
<td>(45.5)</td>
</tr>
<tr>
<td><strong>Right PFE (reps)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 25 (below normal)</td>
<td>26</td>
<td>(42.3)</td>
</tr>
<tr>
<td>≥ 25 (normal)</td>
<td>33</td>
<td>(45.5)</td>
</tr>
<tr>
<td><strong>Left PFE (reps)</strong></td>
<td></td>
<td></td>
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<tr>
<td>&lt; 25 (below normal)</td>
<td>25</td>
<td>(60.0)</td>
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<tr>
<td>≥ 25 (normal)</td>
<td>24</td>
<td>(45.8)</td>
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<tr>
<td><strong>Right or Left PFE (reps)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 25 (below normal)</td>
<td>41</td>
<td>(43.9)</td>
</tr>
<tr>
<td>≥ 25 (normal)</td>
<td>18</td>
<td>(44.4)</td>
</tr>
</tbody>
</table>

ERLP= exercise-related leg pain; BMI= body mass index; ND= navicular drop; PFE= plantar flexor endurance; CI= confidence interval.   
†P<0.001  
‡P<0.0001  
§P=0.01  
**P=0.02  
††P=0.03
identified between females and males for ND > 10 mm. Subjects reporting in-season occurrence of medial leg ERLP had a significantly higher mean ND (TABLE 3) and ND >10 mm (TABLE 2) than subjects not reporting in-season occurrence of medial leg ERLP. Left leg mean ND was greater in subjects with in-season occurrence of medial ERLP (11.6 ± 4.4) compared to subjects without in-season occurrence of medial ERLP (8.0 ± 4.1, p=0.01). Although the difference in mean right leg ND was higher among subjects who reported in-season occurrence of medial ERLP than subjects without medial ERLP, only a non-significant trend was found (10.6 ± 4.2 vs. 8.0 ± 4.0, p = 0.06). Subjects with ND measures >10 mm on either leg had a 4 times (OR = 4.4; 95% CI = 1.0–18.9, p = 0.03) greater odds of developing in-season occurrence of medial ERLP (TABLE 2).

When adjusting for age, gender, BMI and PFE (<25 repetitions), only a previous month history of ERLP (OR = 12.3, 95% CI = 3.1-48.9) was associated with increased likelihood of ERLP during the season in the final multivariate logistic model (TABLE 4). Both ND >10 mm (OR = 6.6, 95% CI = 1.2-38.0) and previous month history of ERLP (OR = 10.3, 95%CI = 1.7-61.9) were associated with occurrence of medial ERLP during the season in the final multivariate logistic model after adjusting for age, gender, BMI and PFE (<25 repetitions) (TABLE 4).

### DISCUSSION

A number of potential risk factors for the development of overuse injuries in distance runners have been identified in the literature. Retrospective and case-control studies have examined differences between subjects with and without the overuse injury of interest, but they have been unable to account for the sequencing of events. The intent of this research was to measure a number of potential risk factors prospectively and determine their association with

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**Table 3. ND and PFE by in-season occurrence of ERLP and medial ERLP**

<table>
<thead>
<tr>
<th>Group</th>
<th>ND Measurement (mean ± SD), mm</th>
<th>PFE Measurement (mean ± SD), reps</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right ND</td>
<td>Left ND</td>
</tr>
<tr>
<td>All (N=59)</td>
<td>8.5 ± 4.1</td>
<td>8.7 ± 4.3</td>
</tr>
<tr>
<td>ERLP (N=26)</td>
<td>8.5 ± 4.3</td>
<td>9.0 ± 4.7</td>
</tr>
<tr>
<td>No ERLP (N=33)</td>
<td>8.6 ± 4.1</td>
<td>8.5 ± 4.0</td>
</tr>
<tr>
<td>Medial ERLP (N=11)</td>
<td>10.6 ± 4.2</td>
<td>11.6 ± 4.4†</td>
</tr>
<tr>
<td>No Medial ERLP (N=48)</td>
<td>8.0 ± 4.0</td>
<td>8.0 ± 4.1†</td>
</tr>
</tbody>
</table>

ND= navicular drop; PFE= plantar flexor endurance; ERLP= exercise-related leg pain; SD= standard deviation. †Significant mean differences (P=0.01)

**Table 4. Adjusted odds ratios for potential risk factors of in-season ERLP and in-season medial ERLP†**

<table>
<thead>
<tr>
<th>Variables in the equation</th>
<th>In-Season ERLP</th>
<th>In-Season Medial ERLP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Odds ratio</td>
<td>(95% CI)</td>
</tr>
<tr>
<td>ND &gt; 10 mm</td>
<td>0.7</td>
<td>(0.2 – 2.6)</td>
</tr>
<tr>
<td>ERLP History (month)</td>
<td>12.3§</td>
<td>(3.1 – 48.9)</td>
</tr>
<tr>
<td>Gender (female)</td>
<td>1.1</td>
<td>(0.3 – 4.2)</td>
</tr>
</tbody>
</table>

ERLP= exercise-related leg pain; ND= navicular drop; CI= confidence interval. †Adjusted for categorical body mass index, age, gender, and plantar flexor endurance (<25 repetitions) §P = 0.03  ‡P <0.0001  **P =0.01
developing ERLP in a group of healthy collegiate runners during the 2009 competitive XC season. Risk factors identified as being significantly associated with overuse injury in runners could then be studied using randomized, controlled designs to examine prevention and treatment methods.

The overall occurrence of ERLP in this sample of 59 cross-country runners was 44.1%, with an equal number of male (n = 13) and female (n = 13) athletes reporting ERLP. Previous prospective studies have reported in-season occurrence of ERLP in athletes ranging between 26% and 48%.4,5,8,49 Medial tibial stress syndrome has been described as exercise-induced, localized pain occurring along the distal two-thirds of the posteromedial tibia.29,50 Prospective studies reporting incidence rates for medial tibial stress syndrome have reported values between 7.5% to 19.8%.11,14,24 Roughly 18% of runners in this study described season ERLP localized to the medial lower leg, although without clinical examination and imaging, other pathologies cannot be ruled out.

The results of this study are consistent with previous studies demonstrating a significant relationship between medial leg pain in runners and excessive pronation.7,8,12,14,25,27,35 Bandholm et al12 retrospectively measured ND in their study and found significantly greater pronation in subjects with MTSS (7.7 +/ - 3.1) compared to controls (5.0 +/ - 2.2, p = .046). Reinking et al5 reported the odds were three times greater for developing ERLP during the competitive season in a group of female collegiate athletes with a ND ≥ 10 mm compared to female collegiate athletes with a ND < 10 mm. Although the results were based on ERLP regardless of location, 75% of subjects localized their pain to the medial leg. Bennett et al14 showed ND and gender correctly predicted the occurrence of MTSS 76% of the time in a group of 125 high school cross-country athletes, with female subjects having larger ND more likely to develop MTSS. These data are consistent with biomechanical and anatomical studies that support the adverse effects of excessive pronation on bony and soft tissues located along the posteromedial tibia.13,15,16,21,22,39,51

Other authors who used ND to measure pronation did not find a significant difference in subjects with and without leg pain.4,5,11,24 In two separate studies, Reinking et al4,5 did not find a difference in ND data based on the in-season occurrence of ERLP. Most subjects in these studies reported bilateral medial leg pain, yet comparison of ND measures did not account for the location of ERLP; therefore their findings are consistent with the current study when considering all leg pain. Two prospective studies measured ND in a group of athletes and failed to find a significant difference between healthy subjects and subjects developing MTSS during the season.11,24 Hubbard et al11 studied a sample of 146 collegiate athletes from six different sports: cross-country, track & field, tennis, soccer, volleyball, and cheerleading. While the majority of athletes developing MTSS (n = 29) participated in cross-country (n = 14) and track & field (n = 9), the potential influence of different sports on the results cannot be ignored. Plisky et al24 excluded subjects with symptoms of MTSS from their study of 105 high school cross-country runners, but did not report the number of subjects excluded based on this criterion. Because prior studies have shown a relationship between MTSS and ND,12,14 it is possible the exclusion of subjects with symptoms of MTSS in the Plisky et al24 study also decreased the number of subjects likely to demonstrate excessive pronation. Differentiating symptoms from injury and comparing ND measures in symptomatic subjects to asymptomatic subjects may provide more insight into potential differences between groups. This study did not find a significant relationship between pronation and in-season occurrence of ERLP localized to the lateral or posterior leg, supporting the influence of excessive pronation on the occurrence of medial leg pain. Failing to find a significant relationship between the in-season occurrence of ERLP and pronation – regardless of location - is likely due to the influence of other intrinsic or extrinsic factors in the development of lateral and posterior leg pain.

Decreased performance and imbalance of lower extremity muscles have been suggested as potential risk factors for overuse injuries in runners.20,52 Fatigue of the ankle plantarflexors has been identified as a possible etiological factor in the development of overuse injuries involving the lower leg.20,52 In a study by Milgrom et al,52 in vivo tibial tension strains and peak gastrocnemius torque were measured before and after a 2 km run and 30 km march. Peak isometric gastrocnemius torque decreased and
medial, mid-tibial tension strains increased significantly as a result of the prescribed activity. Though the authors hypothesized that muscle fatigue resulting in increased tibial tension may lead to overuse injury, they did not find a significant difference in ground reaction forces post-run or post-march. Further, most tests demonstrated decreased peak vertical forces. While it seems likely that muscle fatigue could result in decreased attenuation of ground reaction forces, it is also possible compensatory strategies occur to counteract the effects of muscle fatigue. Future studies need to determine if differences in the degree of muscle fatigue are related to injury as muscle fatigue may result in increases in stress thereby exposing those with structural and biomechanical faults to injury. The degree and timing of fatigue is likely a reflection of conditioning and not a predilection for injury.

Madeley et al \(^{20}\) compared isotonic plantar flexor endurance among a group of symptomatic athletes with medial tibial stress syndrome (MTSS) to a group of matched controls. MTSS was defined as exercise related leg pain occurring in the last week and reproduced with palpation of the postero-medial tibial border. They observed that athletes with MTSS performed significantly fewer heel rise repetitions on average compared to a group of matched controls. Subjects in Madeley’s study reported a chronic history of MTSS (median 15 weeks) with 77% of subjects describing pain resulting in a decrease in everyday activities. The authors acknowledged that reduced activity resulting from pain over an extended period is likely to result in decreased PFE in subjects with MTSS. Therefore, it is possible that reduced PFE was a consequence rather than a risk factor for chronic overuse lower leg pain in athletes. The current study was the first to prospectively measure PFE in non-injured runners prior to their competitive season and found no significant differences in mean heel-rise repetitions between runners developing in-season ERLP and runners remaining free of leg pain. Similar findings were found for medially located in-season occurrence of ERLP, suggesting that reduced PFE is not associated with the increased likelihood of MTSS.

Lunsford et al suggested using twenty-five repetitions as a reference standard for isotonic plantar flexor endurance at a rate of one heel rise every two seconds.\(^{46}\) In this study, the subjects demonstrated a higher mean PFE on the right leg (26.6 ± 11.5 repetitions) and lower mean PFE on the left leg (22.9 ± 8.5 repetitions) compared to the reference standard, although the normal value of 25 repetitions fell within one standard deviation of the mean. Although the subjects in this study were healthy collegiate runners, their mean PFE values are not greater than those reported in other studies using subjects who are older, injured or are not collegiate athletes.\(^{20,45,46}\) The current study was the first to examine and report risk of developing in-season occurrence of ERLP based on exposure by using Lunsford’s recommended 25 repetitions as a cut-point. Subjects who performed less than 25 repetitions did not significantly increase the risk of incurring in-season ERLP in this cohort of collegiate XC runners regardless of leg pain location. Performing less than 25 heel-rise repetitions, however, was significantly related to gender, with 82.1% of females testing below the reference standard. While prior studies have reported female gender as a significant factor for overuse injury, the authors of the current study are unaware of any other studies reporting significant differences in PFE between male and female subjects.\(^{5,7,14,24,40}\)

These data revealed a significant relationship between in-season occurrence of ERLP and history of ERLP during the past month or year. History of previous injury has been reported in numerous studies as a significant risk factor for recurring leg pain in runners.\(^{4,5,11,41,49}\) As injury is often times defined as an inability to perform normal activities or time loss from activity, the authors further classified leg pain using the Nirschl pain phase scale for overuse injuries.\(^{32,33}\) Athletes describing their leg pain as four or greater on the Nirschl phase pain scale were considered to have interfering leg pain because their pain resulted in alteration of athletic or daily activities. A significant relationship was found between runners with a history of ERLP and in-season occurrence of interfering ERLP. An important observation was that 100% of runners denying a history of ERLP over the last year remained painfree during the course of the competitive season, and 75% of runners with a history of ERLP in the previous month developed in-season occurrence of interfering ERLP. Thus, identifying runners with a history of interfering ERLP prior to the competitive season may allow for earlier prevention and intervention strategies.
Several limitations of study are noted. An a priori power analysis determined that a sample size of 262 subjects was needed to detect a statistically significant association between navicular drop and ERLP. However, the final sample size of this study was 59 subjects completing all measures. Despite the small sample size the strength of the relationship between medial ERLP and pronation likely resulted in the significant findings. An underpowered study increases the likelihood of committing a Type II error and not finding a significant difference when one truly exists. Future studies should include larger sample sizes to improve the strength of the study and reduce the risk of committing a Type II error.

Exercise-related leg pain is a regional description of pain and as such does not differentiate between overuse pathologies commonly associated with endurance activities. Identifying risk factors for specific overuse injuries – such as MTSS - may allow for more direct intervention. On the other hand, interventions are directed at structural and biomechanical impairments identified during the examination process, and not at a specific diagnosis. A dynamic, recursive model for sports injury takes into consideration the interaction of modifiable and non-modifiable risk factors during repeated exposure to environmental stress.

Another limitation of this study involves the timing of athlete’s reporting ERLP. Subjects were asked to complete a follow-up survey at the completion of their season regardless of when they experienced ERLP. Athletes experiencing ERLP early in the season may have a more difficult time recalling details regarding location and intensity of their pain. Having the athletes complete a questionnaire during the season at frequent intervals likely would have allowed for increased accuracy in the identification of the onset and severity of ERLP. Differences in training and the number of exposures each subject experienced during the season further limited the study findings. Tracking exposures and mileage would provide further detail regarding the influence of training volume on the development of overuse injury. Finally, the subjects in this study were on average 19.3 years of age and rostered on a collegiate cross-country team during the 2009 season. Generalizing the results of the current study to the larger running community is likely limited due to the unique training and fitness characteristics of this somewhat unique population.

In conclusion, isotonic ankle plantar flexor endurance and excessive pronation were not risk factors for in-season occurring ERLP in this group of collegiate cross-country runners. When accounting for the location of leg pain, excessive pronation was found to be a significant risk factor for in-season occurrence of ERLP localized to the medial leg. A history of ERLP was associated with increased risk of developing ERLP and interfering ERLP during the competitive season. Excessive pronation, i.e., navicular drop greater than 10 mm, and a history of ERLP were found to be significantly associated with in-season occurrence of ERLP localized to the medial leg. Future studies examining the effect of strength and pronation on ERLP should include a larger sample of collegiate cross-country runners as well as in other competitive and recreational running populations.

REFERENCES


ABSTRACT

Purpose/Background: A variety of methods exist to measure ankle dorsiflexion range of motion (ROM). Few studies have examined the reliability of a novice rater. The purpose of this study was to determine the reliability of ankle ROM measurements using three different techniques in a novice rater.

Methods: Twenty healthy subjects (mean ± SD, age = 24 ± 3 years, height = 173.2 ± 8.1 cm, mass = 72.6 ± 15.2 kg) participated in this study. Ankle dorsiflexion ROM measures were obtained in a weight-bearing lunge position using a standard goniometer, digital inclinometer, and a tape measure using the distance-to-wall technique. All measures were obtained three times per side, with 10 minutes of rest between the first and second set of measures. Intrarater reliability was determined using an intraclass correlation coefficient (ICC2,3) and associated 95% confidence intervals (CI). Standard error of measurement (SEM) and the minimal detectable change (MDC) for each measurement technique were also calculated.

Results: The within-session intrarater reliability (ICC2,3) estimates for each measure are as follows: tape measure (right 0.98, left 0.99), digital inclinometer (right 0.96; left 0.97), and goniometer (right 0.85; left 0.96). The SEM for the tape measure method ranged from 0.4-0.6 cm and the MDC was between 1.1-1.5 cm. The SEM for the inclinometer was between 1.3-1.4° and the MDC was 3.7-3.8°. The SEM for the goniometer ranged from 1.8-2.8° with an MDC of 5.0-7.7°.

Conclusions: The results indicate that reliable measures of weight-bearing ankle dorsiflexion ROM can be obtained from a novice rater. All three techniques had good reliability and low measurement error, with the distance-to-wall technique using a tape measure and inclinometer methods resulting in higher reliability coefficients (ICC2,3 = 0.96 to 0.99) and a lower SEM compared to the goniometer (ICC2,3 = 0.85 to 0.96).

Key Words: goniometry, inclinometer, talocrural joint

Level of Evidence: 2b
INTRODUCTION
There are a number of methods and tools available to measure ankle dorsiflexion range of motion (ROM) in both non-weight-bearing and weight-bearing positions. Weight-bearing measures are thought to more accurately reflect the available ROM during functional activities such as walking, running, or stair ambulation, and may be more reliable (ICC = 0.93-0.96) than measures obtained in a non-weight-bearing position (ICC 0.32-0.72).2 Most measurement techniques for ankle dorsiflexion ROM include the use of a standard goniometer,3,4 an inclinometer,5-8 or a tape measure,1,9,10 and have varying levels of technical difficulty for the individual obtaining the measures.

The goniometer is inexpensive and commonly used in clinical environments, but also requires the greatest degree of technical proficiency, due to the necessity of aligning the axis with the joint fulcrum and positioning the two arms with established reference points.3 The technical proficiency required to obtain measures of ROM with a goniometer may contribute to lower reported reliability values (ICC = 0.65-0.89) when compared to other measurement methods (ICC = 0.84-0.95).11,12 Alternatively, an inclinometer may be used to measure ankle dorsiflexion ROM and only requires the rater to identify the tibial tuberosity for consistent inclinometer placement in a weight-bearing position1,6,8 or to identify the base of the fifth metatarsal in a non-weight-bearing position.5 The inclinometer may utilize a dial, bubble, or digital display to provide the angle of the slope relative to the ground. The digital display may potentially reduce recording errors, since the display provides a single numeric value versus requiring the rater to determine the location of the dial or bubble relative to the nearest tick-mark. The use of the inclinometer may improve reliability measures (ICC = 0.84 to 0.95) for novice raters, when compared to goniometer (ICC = 0.65 to 0.77) measures, in a non-weight-bearing position.12 To the authors’ knowledge, only one study11 has compared novice and expert raters using a digital inclinometer versus a goniometer in a weight-bearing position; the study demonstrated similar reliability between techniques (ICC = 0.89 goniometer, 0.88 digital inclinometer). There is no consensus regarding the preference of using a goniometer or inclinometer for the measurement of ankle dorsiflexion ROM. Although the inclinometer is easy to use, the cost is usually higher than a standard goniometer.

An additional way to quantify ankle dorsiflexion ROM is with a tape measure.1,13 This method utilizes the knee-to-wall principle, in which the subject performs a weight-bearing lunge. The patient places the test foot on a tape measure perpendicular to the wall and lunges forward so the knee touches the wall. The foot is moved away from the wall until the knee can only make slight contact with the wall while the foot remains flat on the ground. This position places the ankle in maximal dorsiflexion, and the distance from the great toe to the wall is measured in centimeters, with each centimeter corresponding to approximately 3.6° of ankle dorsiflexion.1 This method is inexpensive, can be performed in a variety of settings, and does not require the technical proficiency associated with a goniometer or inclinometer. The tape measure method is also hypothesized to be more sensitive to change compared to measures of motion in degrees.14

Due to the different levels of technical proficiency required for each measurement method, some techniques may be better performed by raters with more experience, yielding greater measurement reliability.31 Therefore, it is essential to determine which measurement techniques a novice rater would be able to perform reliably, and which techniques require additional practice and experience. Obtaining a better understanding of the reliability and error associated with each technique would provide valuable information for individuals who work with novice raters. Therefore, the purpose of this study was to compare the reliability of three different ankle ROM measurement techniques performed by a novice rater with no previous experience with any of the techniques.

METHODS
Experimental Approach
The approach was a pre/post-test design over a single testing session. A novice rater (fourth year exercise science student) performed all measurement techniques. The novice rater underwent approximately three hours of training with an experienced rater to standardize testing procedures and practiced these procedures on five volunteers prior to beginning the study.

Subjects
Twenty healthy adults (seven males, 13 females; mean ± SD, age = 24 ± 3 years, height = 173.2 ± 8.1 cm, mass = 72.6 ± 15.2 kg) volunteered to participate in this
study. Participants were recruited through university announcements and mass e-mails. Prior to enrollment, participants completed an Institutional Review Board-approved informed consent form and a health history form. Exclusion criteria included any lower extremity injury or surgery within the past six months.

**Procedures**
Maximal ankle dorsiflexion ROM was measured in a weight-bearing position (lunge) using a standard 7-inch, flat, clear plastic goniometer with 2° increments, a digital inclinometer with 1° increments (Acumar Single Digital Inclinometer; Lafayette Instrument Company, Lafayette, IN), and a metric tape measure with the ability to measure to 0.1 cm. All testing was completed with the participant barefoot. Three separate measures were obtained on the right and left ankles using each technique, with the initial side determined using a randomized chart. All measurements (goniometer, inclinometer, and tape measure) were obtained during the same session and, after obtaining the first set of measures, the participant rested for 10 minutes and the test sequence was repeated.

**Weight-Bearing Lunge**
Ankle dorsiflexion ROM was measured using a weight-bearing lunge facing a wall (Figure 1). The weight-bearing lunge was performed in a standing position with the heel in contact with the ground, the knee in line with the second toe, and the great toe 10 cm away from the wall. Balance was maintained by allowing contact with the wall using two fingers from each hand. Participants were asked to lunge forward, directing their knees toward the wall (in line with the second toe) until their knees touched the wall. The foot was progressed away from the wall 1 cm at a time until they were unable to touch the wall with their knee without lifting the heel from the ground. Once the knee was not able to touch the wall, the foot was progressed in smaller increments toward the wall until the knee made contact with the wall with the heel in contact with the ground. This progression toward the wall allowed a measurement to be obtained to the nearest millimeter. If the participant was not able to touch their knee to the wall without lifting the heel from the ground at the initial 10 cm start position, the participant was asked to move his or her foot forward toward the wall 1 cm at a time until they could touch their knee to the wall while keeping the heel on the ground. At the point when the knee made contact with the wall, the foot was progressed in smaller increments away from the wall to allow a measure to be obtained to the nearest millimeter. Maximal dorsiflexion ROM was defined as the maximum distance of the toe from the wall while maintaining contact between the wall and knee without lifting the heel. Heel contact with the ground was monitored by the rater by lightly placing their fingers on the heel to feel for heel movement, while also visually examining the heel for movement. When the participant reached the final lunge position, a digital inclinometer (Figure 2) was placed at the tibial tuberosity and was used to measure the angle of the tibia relative to the ground. Prior to measurement for each subject, the goniometer was zeroed relative to the horizontal (versus the vertical default setting) by aligning the goniometer with a wall that was perpendicular to the floor (90°). This was done to ensure a consistent starting point across

**Figure 1.** Initial participant position for the weight-bearing lunge. The great toe is 10 cm from the wall and the knee is in line with the second toe. The participant is allowed to maintain contact with the wall using two fingers from each hand to maintain balance.
all subjects. While the participant maintained his or her maximal dorsiflexion position, a standard goniometer (Figure 3) was aligned with floor (stable arm) and through the shaft of the fibula (mobile arm) by visually bisecting the lateral malleolus and the fibular head.11 Finally, the rater recorded the distance of the great toe from the wall to the nearest 0.1 cm. Participants were allowed three practice trials per limb and completed three test trials per limb, with the average of each side used as the representative value for data analysis.

**Table 1. Weight-Bearing Lunge Dorsiflexion Range of Motion Measurement Averages.**

<table>
<thead>
<tr>
<th>Test</th>
<th>Mean±SD</th>
</tr>
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<tbody>
<tr>
<td>Tape Measure</td>
<td>9.5 ± 3.1 cm</td>
</tr>
<tr>
<td>Digital Inclinometer</td>
<td>38.8 ± 5.2°</td>
</tr>
<tr>
<td>Goniometer</td>
<td>43.2 ± 5.8°</td>
</tr>
<tr>
<td>Averages were determined using data from each side (right and left) during trial 1</td>
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</tbody>
</table>

**RESULTS**

The descriptive data (X ± SD) for the composite measures of ankle dorsiflexion ROM are presented in Table 1. Descriptive statistics (X ± SD) for the right and left side, as well as trial 1 and 2 for each technique, are presented in Table 2. Scatterplots (Figures 4-6) were constructed to compare measurement techniques using data obtained from both limbs during Trial 1. The within-session intrarater reliability (ICC<sub>2,3</sub>) estimates ranged from 0.85 (goniometer) to 0.99 (tape measure) (Table 3). The SEM for the goniometer and inclinometer ranged from 1.3° to 2.8° with an MDC of 3.7° to 7.7°. The SEM for the tape measure method ranged from 0.4 cm to 0.6 cm (1.6° to 2.5°), and the MDC was between 1.1 cm and 1.5 cm (4.5° to 6.1°).

**DISCUSSION**

This was the first study to examine the reliability of three different techniques to measure ankle dorsiflexion ROM in a weight-bearing position using a novice...
The results showed good reliability (ICC>0.85) among all three techniques, with the distance-to-wall and inclinometer methods resulting in higher reliability coefficients (ICC=0.96 to 0.99) compared to the goniometer (ICC=0.85 to 0.96). In addition, all three measurement techniques resulted in low measurement error (SEM=0.4-0.6cm with the tape measure, 1.8-2.8° with the goniometer, 1.3-1.4° with the digital inclinometer). These findings suggest that an individual with little training can obtain reliable measures of weight-bearing ankle dorsiflexion ROM utilizing a goniometer, inclinometer, or tape measure.

The reliability estimates obtained in this study (ICC>0.88) are consistent with those obtained by other authors1,2,4,5,9 who utilized raters of varying expe-

<table>
<thead>
<tr>
<th>Test</th>
<th>Side</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>P Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tape Measure</td>
<td>Right</td>
<td>9.6 ± 2.9 cm</td>
<td>9.7 ± 2.9 cm</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>9.4 ± 3.3 cm</td>
<td>9.6 ± 3.4 cm</td>
<td>0.27</td>
</tr>
<tr>
<td>Digital inclinometer</td>
<td>Right</td>
<td>38.2 ± 4.5°</td>
<td>39.0 ± 4.7°</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>39.3 ± 5.8°</td>
<td>39.9 ± 5.5°</td>
<td>0.22</td>
</tr>
<tr>
<td>Goniometer</td>
<td>Right</td>
<td>43.4 ± 4.7°</td>
<td>43.9 ± 5.3°</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>43.1 ± 6.8°</td>
<td>44.1 ± 6.6°</td>
<td>0.07</td>
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</table>

*There were no significant differences between measures obtained during Trial 1 and Trial 2.
rience. Previous studies\textsuperscript{1,11} have utilized novice raters and compared them to more experienced raters, but have not determined which technique yields the best reliability for a novice rater. Bennell et al.\textsuperscript{1} used a second year physical therapy student as their novice rater and found good reliability (0.99 CI: 0.97-0.99) when measuring weight-bearing ankle dorsiflexion with a digital inclinometer and the distance-from-wall measurements 0.97 (0.90-0.99). Munteanu et al.\textsuperscript{11} used a senior undergraduate student as their novice rater and found good reliability (ICC=0.77) for ankle dorsiflexion ROM measures in a weight-bearing position with the knee extended using a digital inclinometer, but these reliability estimates were slightly lower than reliability among experienced raters (ICC=0.88). The results of this study demonstrate good reliability (ICC≥0.85) among all three techniques, with the distance-to-wall and inclinometer methods resulting in higher reliability coefficients (ICC=0.96 to 0.99) compared to the goniometer (ICC=0.85 to 0.96).

The methods outlined in this study for measuring ankle dorsiflexion ROM vary slightly from methods previously proposed by other authors.\textsuperscript{1,5,7,10,11} It has been suggested that subtalar and foot position, specifically pronation, may allow the ankle to achieve greater angles of dorsiflexion ROM.\textsuperscript{18,19} Although the authors did not specifically place the foot in a subtalar neutral position or utilize a small wedge placed under the medial aspect of the foot to maintain a more neutral position of the subtalar joint,\textsuperscript{20,21} we did have the subject progress his or her knee in an anterior direction (toward the wall) in line with the second toe.\textsuperscript{10,22} Alternatively, a vertical line, perpendicular to the tape measure, can be drawn on the wall\textsuperscript{7} and may serve as a visual target for the knee to progress toward the wall and to maintain foot alignment.

A second methodological difference was the placement of the digital inclinometer. The tibial tuberosity,\textsuperscript{6} 15 cm distal to the tibial tuberosity,\textsuperscript{1} a mid-point between the tibial tuberosity and the talocrural joint,\textsuperscript{11} and the distal lateral aspect of the tibia\textsuperscript{7} have all been used as anatomical landmarks for placement of the inclinometer. Since the measure of ankle dorsiflexion ROM obtained is the angle of the tibia relative to the ground (horizontal), it is possible that any point along the tibia may be used to obtain a measure of ankle dorsiflexion ROM. In this study, the authors utilized the tibial tuberosity as a bony landmark for placement of the inclinometer\textsuperscript{6} because we felt that this location could be consistently and easily identified by a novice examiner. Identification of a single bony landmark may also be more desirable for clinicians versus identifying a bony landmark and then measuring to a distant site, such as 15 cm distally, then placing the inclinometer on the tibia.\textsuperscript{1} Although the tibial tuberosity is not an entirely flat surface, the foot of the inclinometer was able to make contact with this landmark, while the other foot of the inclinometer made contact with the tibial crest.

When performing a weight-bearing lunge near a wall, the placement of a digital inclinometer on the tibial tuberosity may leave little clearance between the wall and inclinometer. Although this was not an issue in this study, the authors suggest that, when utilizing an inclinometer, the weight-bearing lunge be performed away from a wall.\textsuperscript{6} While a number of anatomical locations have been utilized for placement of the inclinometer, the optimal placement has not been determined. Despite the fact the methodology utilized in this study varies slightly from previous studies,\textsuperscript{1,5,7,10,11} it should be noted that all measurement techniques demonstrated good reliability between the first and second trials when performed by a novice rater.

<table>
<thead>
<tr>
<th>Table 3. Intrarater Reliability (ICC\textsubscript{2,3}) and Measurement Error for Dorsiflexion Range of Motion Measurements.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Right Side</strong></td>
</tr>
<tr>
<td><strong>Test</strong></td>
</tr>
<tr>
<td>Tape Measure</td>
</tr>
<tr>
<td>Digital inclinometer</td>
</tr>
<tr>
<td>Goniometer</td>
</tr>
</tbody>
</table>

Abbreviations: ICC= interclass correlation coefficient; CI= confidence interval; SEM= standard error of measure; MDC= minimal detectable change.
The composite mean for the inclinometer measurement technique (38.8° ± 5.2°; Table 1) is consistent with previously reported normative values (30°-50°) for healthy individuals.1,5,23 The ROM value for the tape measure method (9.5 cm) expressed in centimeters is lower than what has previously been reported (11-14 cm),1,2,9 but the MDC values (1.1 to 1.5 cm) derived in this study are consistent with the results of previous studies. The composite measure of ankle dorsiflexion obtained using the goniometer in the current study was 43.2°, which is considerably higher compared to the findings of Johnson et al.24 and Burns and Crosbie,23 who both reported values of 32° for healthy subjects. The age ranges in the previous studies (19-30 years)23,24 were similar to the age range for our subjects (20-34 years). The differences in the results for the goniometer in the current study and those of Johnson et al.24 and Burns and Crosbie23 may be due to slight differences in control of foot position during testing. In the current investigation, we did not attempt to control for foot position (subtalar neutral), whereas previous studies using goniometers have specifically controlled for subtalar joint position.18,21,23,24

Although all three measurements in this study were obtained almost simultaneously, there were slight differences in the point estimates when using the goniometer and inclinometer. Differences may have been due to the anatomical reference points utilized for each measure.25 In this study, the mobile arm of the goniometer was aligned with the fibular head3,4 and the digital inclinometer was aligned with the tibial tuberosity.6,8 The difference between inclinometer and goniometer measures was slightly less than 5° (inclinometer 38.8°; goniometer 43.2°). Utilizing the tibial tuberosity has been shown to result in ROM measures that are approximately 5° greater than using the fibular head as an anatomical landmark.25 Our results were actually 5° greater for the inclinometer when compared to the goniometer. It is not known whether the differences between the goniometer and inclinometer measures are due to differences in methods used to obtain ROM measures,25 or potentially due to a systematic rater error, such as consistent goniometer misalignment. Regardless, both goniometer and inclinometer measures are within the previously reported normative values (30-50°).1,5,23 The MDC for inclinometer measures was 3.7° and 3.8° for the left and right ankle, respectively, and is within the range (1.5° and 6.4°) reported in previous studies.5,7 The MDC for the tape measure method was 1.1-1.5 cm, which is also consistent with values (0.4-1.4 cm) reported in previous studies.1,9

Although the weight-bearing lunge is commonly used to determine dorsiflexion ankle ROM,1,4-10 there is no universal agreement regarding which measurement device (goniometer, inclinometer, tape measure) is most preferred. The results of this study indicated that the digital inclinometer was more sensitive to changes in motion than the goniometer (inclinometer MDC = 3.8° versus goniometer MDC = 7.7°). Differences between the tape measure and digital inclinometer are not as evident since different units of measure are utilized (centimeters versus degrees). Previous data1 has been used to extrapolate a conversion equation in which 1 cm of distance from the toe to the wall roughly equals 3.6° of ankle dorsiflexion ROM.1 However, the results of this study indicate that every 1 cm of distance equals 4.1° of dorsiflexion ROM. It is possible that a simple conversion equation may not be possible, and future studies should determine whether a more accurate conversion equation is possible. While the reliability estimates and absolute measures of ROM between the three techniques were consistent with previous research, the use of a single novice rater performing three specific techniques was unique to this study.

Measurement techniques in this study were obtained exclusively in a weight-bearing position, and measures of weight-bearing ROM may not be possible with some clinical populations. Reliability for measures obtained in a non-weight-bearing position have been shown to range from poor (ICC = 0.32) to good (ICC = 0.97),2,24,26-30 but it has been suggested by Venturini et al.2 that measures in a weight-bearing position may provide greater reliability estimates (non-weight-bearing ICC = 0.32-0.72; weight-bearing ICC = 0.93-0.96). Although ROM determined in a weight-bearing position may be more indicative of the available functional dorsiflexion ROM,1 it does not measure motion at a specific joint (talocrural, subtalar, tarsal). We did not attempt to control for pronation/supination, which may have adversely
influenced the available dorsiflexion ROM. If it is necessary to determine ROM at a specific joint, clinicians and researchers should attempt to restrict motions, such as pronation, by using a towel, or measure ROM in a non-weight-bearing position.

Limitations to this study include a small sample size of 20 participants, all of whom were healthy and between the ages of 20 and 34 years. All of the subjects tested were free of ankle or lower extremity injury, which could have aided the ease of results. Therefore, it is not possible to generalize our findings to individuals outside of this age range or to individuals with joint pathology. Further research is needed across a broad age range (youth to geriatric) and on individuals with a history of joint pathology (i.e., ankle sprain).

Other limitations to the study are that only one novice rater was used, and that the order of measurement techniques was not randomized. Therefore, it is possible that the rater became more proficient with the measurement techniques as the study progressed. In addition, since the rater was not blinded to the measurements, it is possible that his or her knowledge of the initial values may have influenced subsequent measures. The authors felt that, since the three measurement techniques require the rater to make a judgment regarding the number of degrees indicated by the goniometer or inclinometer, blinding the rater to these measures would have limited the generalizability of the study. Future studies may be warranted to determine whether a learning curve is present, and may consider blinding the assessor. Finally, this study did not investigate the reliability of an experienced rater. Although previous studies have provided reliability estimates ranging from 0.88 to 0.99, for experienced raters utilizing these measurement techniques, additional research may provide a better understanding of the relative differences in reliability between novice and experienced raters.

CONCLUSION
The results of this study indicated that a novice rater, with no prior experience using three different ankle ROM measurement techniques, can obtain reliable estimates of ankle dorsiflexion ROM in healthy individuals using a goniometer, digital inclinometer, or tape measure method. The measurements were obtained using a standardized protocol, which can be easily replicated in a clinical or research environment, and the SEM and MDC scores for the three techniques were low, which provides some level of confidence that changes in ROM following intervention are beyond that of measurement error. The reliability coefficients for the digital inclinometer and tape measure techniques were higher (ICC_{2,3}=0.96 to 0.99) compared to the goniometer (ICC_{2,3}=0.85 to 0.96), and the inclinometer resulted in the lowest MDC; therefore, the inclinometer may be preferred over the tape measure and goniometer techniques, particularly when measuring changes in ROM before and after injury or intervention.

REFERENCES


ABSTRACT

**Purpose/Hypothesis:** The kinematic sequence of the golf swing is an established principle that occurs in a proximal-to-distal pattern with power generation beginning with rotation of the pelvis. Few studies have correlated the influence of peak pelvis rotation to the skill level of the golfer. Furthermore, minimal research exists on the strength of the gluteal musculature and their ability to generate power during the swing. The purpose of this study was to explore the relationship between peak pelvis rotation, gluteus medius and gluteus maximus strength, and a golfer's handicap.

**Subjects:** 56 healthy subjects.

**Material/Methods:** Each subject was assessed using a hand-held dynamometry device per standardized protocol to determine gluteus maximus and medius strength. The K-vest was placed on the subject with electromagnetic sensors at the pelvis, upper torso, and gloved lead hand to measure the rotational speed at each segment in degrees/second. After K-vest calibration and 5 practice swings, each subject hit 5 golf balls during which time, the sensors measured pelvic rotation speed.

**Results:** A one-way ANOVA was performed to determine the relationships between peak pelvis rotation, gluteus medius and gluteus maximus strength, and golf handicap. A significant difference was found between the following dependent variables and golf handicap: peak pelvis rotation ($p=0.000$), gluteus medius strength ($p=0.000$), and gluteus maximus strength ($p=0.000$).

**Conclusion:** Golfers with a low handicap are more likely to have increased pelvis rotation speed as well as increased gluteus maximus and medius strength when compared to high handicap golfers.

**Clinical Relevance:** The relationships between increased peak pelvis rotation and gluteus maximus and medius strength in low handicap golfers may have implications in designing golf training programs. Further research needs to be conducted in order to further explore these relationships.

**Key Words:** golf, gluteus maximus, gluteus medius, peak pelvis rotation
INTRODUCTION

The timeless subject of how to improve one’s golf swing has been examined extensively. Previous authors have investigated proximal to distal kinematics, coiling, and the efficiency of energy transfer through the principle of work, the x-factor, and rotational speed.

Proximal to distal kinematic sequencing has been demonstrated in several rotational sports such as tennis, baseball, soccer and golf. The sequence of the golf swing is proposed to occur in a proximal to distal pattern where “motion is initiated with the larger, heavier, slower central body segments; then, as the energy increases, the motion proceeds outward to the smaller, lighter and faster segments.” In the literature, proximal to distal sequencing may also be called kinetic linking or the kinematic sequence. The latter, kinematic sequence, is the preferred term of Phil Cheetham, head biomechanist and director of the Titlist Performance Institute Biomechanics Advisory Board. Cheetham focuses on the transition and downswing phases of the golf swing when assessing kinematic sequence.

The transition phase of the golf swing occurs quickly and is the movement from backswing into downswing, during which each body segment changes direction. In proper kinematic sequencing, the order of body segment change in direction should be as follows: pelvis, thorax, lead arm, and then club. This occurs through the power of the leg muscles rotating the pelvis forward towards the target. The pelvis then accelerates, but quickly decelerates, transferring energy to the thorax. This pattern is continued with an acceleration and deceleration of the thorax which transfers energy to the lead arm and finally to the club. This order should continue throughout the downswing, during which all body segments are accelerating and decelerating with specific timing to bring the club to impact with the ball at maximum speed. (Figure 1). The kinematic sequence impacts energy transfer and power during the golf swing as well as compensation by other body parts. If the kinematic sequence is out of order, not only can energy be lost; which then decreases speed, power, accuracy, and consistency, but other body segments can begin to compensate as well.

It is important to analyze the kinematic sequence for optimal performance, and also to avoid injury. Cheetham has defined the golf swing as a delicate balance between successive postures and forces that must be developed in a coordinated sequence over a very short period of time. The pelvis and spine are the central transfer point between the lower and upper body, and thus, are subject to an extreme amount of force during the golf swing. Therefore, it is important for hip and pelvis rotation to occur in a smooth and coordinated fashion in order to avoid compensations for poor spine mechanics.

Lephart indicated that following an exercise program mimicking the golf swing may improve the sequencing pattern of the pelvis, shoulders, and arms. Although the primary purpose of their research and eight-week golf-specific exercise program was to increase physical fitness and improve swing mechanics and overall golf performance in recreational golfers, the researchers also found improvements in swing kinematics. They attributed the enhanced kinematic sequence to “motor learning effects and improvements in physical characteristics specific to golf.” As a result, the researchers suggested that the improved sequencing pattern may have had an impact on the greater efficiency in power transfer to the club and ball exhibited by some of the subjects.

The coiling principle, another theory of kinematic sequencing, is currently utilized by many golf pros. Coiling seeks to create torso-pelvic separation by maximizing upper torso rotation and minimizing pelvic rotation during the backswing. Steven Nesbit, a mechanical engineering professor, used the principles of physics to discover that during the golf swing the body is synonymous with a spring or coil, acting in a way that ultimately increases ball velocity and driving distance. A centrifugal force is created by the upper body coiling around the pelvis. The axis of rotation is fixed around the spine. As the upper body coils around the pelvis, the potential energy increases. The energy transferred from each body segment during the downswing becomes greater in magnitude as the energy progresses to further distal body segments. The sequencing of increased kinetic energy follows the pattern of the legs, hips, low back, upper back, shoulders, arms, and wrists. Nesbit and Serrano also found that the generation of power during the back swing comes primarily from the spine and hip joints. This coiling pattern is seen in most pro golfers as it is essential in generating power during the golf swing.
A more recent development in kinematic sequencing in golf called the “X-factor” is used to describe the rotation of shoulders with relation to hips at the top of the golf swing. Studies have shown that an increase in upper-torso rotational velocity and an increase in the X-factor have the potential to increase club head velocity, which in turn will increase the carrying distance of the ball as long as the rest of the swing mechanics are timed correctly.

Most studies on the X-factor have not considered the events that occur after the club progresses into the downswing phase; however, one study by Cheetham et al has addressed this. Cheetham et al compared the X-factor at the top of the backswing and early downswing between highly skilled and less skilled golfers. They found that although the X-factor was not significantly larger in highly skilled golfers at the top of the backswing, it was significantly larger in early downswing.

Highly skilled golfers have a stretch which inhibits the X-factor from rapidly closing during downswing. This X-factor stretch is the amount of separation between the shoulders and the hips at the beginning of the downswing. Cheetham showed that less skilled players tend to have very little separation between their hips and shoulders, and they tend to rotate towards the target at the same time. Highly skilled players are more inclined to rotate their hips significantly faster during the early downswing causing the muscles of the torso to stretch. The pelvis of highly skilled golfers also had a higher rotational velocity which caused an increase in the X-factor. It is thought that “a rapid rotation of the pelvis in early downswing may trigger sensitive stretch receptors in muscles to quickly shorten” thus creating a more forceful contraction to drive the ball. Due to the stretch between the shoulders and the torso at the top of the backswing there is a storage of elastic energy in the torso which is then released resulting in a stronger contraction. Ultimately, the authors of this study concluded that the X-factor stretch, not the X-factor proposed by earlier research, causes an increase in force production during the downswing which in turn increases the club head speed at impact.

The concepts of the kinematic sequence, coiling, and the X-factor stretch have proven to be very useful in golf swing analysis. Peak pelvis rotation velocity was included in Cheetham's study which compared the kinematic sequence parameters between amateur and professional golfers. The professional golfers had an average peak pelvic rotation velocity of 477 ± 53 degrees/second while the mean for the amateurs was only 395 ± 53 degrees/second. These results indicated that a significant difference (p = 0.011) existed in peak pelvis rotation velocity between golfers of two skill levels. Cheetham proposed that ideally a 1.5 transfer ratio should exist between the pelvis to thorax and thorax to arm. A slightly higher transfer ratio of 2.2-2.4 is optimal for the transfer of energy between the lead arm to club. In other words, each segment should increase in speed (degrees/sec) to 150% of the proximal connecting segment. Assuming that this transfer ratio holds true, it is easy to see how an increase in peak pelvic rotation can greatly increase club head speed and in turn, power.

Building on Cheetham’s research, a more thorough understanding of peak pelvic rotation and its role in golf is needed. The purpose of this research was to determine if there was a difference in peak pelvis rotation speed between high and low handicap golfers. A secondary purpose was to determine if there was a significant difference in gluteus maximus and gluteus medius strength between high and low handicap golfers. Based on the purposes of this study, it was hypothesized that peak pelvis rotation speed would be significantly faster and gluteus maximus and gluteus medius strength would be significantly higher in low handicap golfers when compared to high handicap golfers.

METHODS
The subject pool included volunteer participants from the current PGA and LPGA tour, Belmont University’s golf teams, recreational golfers, and non-golfers. Every subject was provided with an informed consent document. The subjects that participated in the study were asked a series of questions regarding his/her golf handicap. The subjects were then assigned to a high handicap group (≥18; N=18) or low handicap (<5; N=38) group. Those with a handicap between 6 and 17 were excluded from the study. The subjects that reported being new to golf and did not have USGA handicap were assumed to have a
Those that had an injury or health restrictions at the time of the study were also excluded. After the paperwork and inclusion/exclusion criteria were determined, each subject participated in a lower quarter screen including a functional movement assessment as well as dermatome and myotome testing in order to screen for injury. All subjects passed the screen to rule out injury. After the screening, manual muscle testing was performed on each individual with a hand held dynamometer (Nicholas Manual Muscle Tester, Lafayette Instruments, Lafayette, IN). Manual muscle testing was performed using the standard protocols and positions for gluteus maximus and gluteus medius on the right and left side (Figure 2). Results of the manual muscle tests were normalized to body weight for each subject. Next, each subject was given a golf specific warm-up session (Table 1). The K-vest was then placed on the subject and calibrated. Each subject was allowed 5 practice swings using a 7 or 8 iron. The subject then took 5 test swings while the K-vest software collected and recorded the data of each swing. The subjects' average peak pelvis rotation speed was calculated from the 5 swings.

**INSTRUMENTATION**

The K-vest (Bentley Kinematics, Exton, PA) is a motion analysis system that was designed specifically for golf. The system includes 3 wireless motion tracking sensors (each weighing less than 2 ounces), hip and shoulder garments, a receiver, and software (video camera and laptop are not included). The 3 sensors were placed on different parts of the body: the hip sensor was centered on the back of the sacrum, and was secured in place by the hip garment; the shoulder sensor was placed in between the shoulder blades between spinal levels T3-T5, secured by the shoulder garment; and the wrist sensor was attached to the player’s golf glove of the lead wrist (see Figure 3). Each individual sensor is composed of a bundle of 9 smaller sensors, which allow for measurement of the golf swing in 3 dimensions. The measurements and data were transmitted to a laptop with the K-vest software, through which real-time video was analyzed. The technology of K-vest software is backed by the Titleist Performance Institute (TPI) 3D algorithms and included the TPI 3D
Reliability and validity have been assessed and found to be comparable to the gold standard motion analysis video capture methods, and the US Military has employed the K-vest for training and research due to the extraordinary accuracy and durability of the K-sensors. The research team was instructed on the use of the K-vest and its software by the developers. This system was used to calculate the peak pelvis rotational speed which was then correlated with the golfer's handicap.

**RESULTS**

**Data Analysis**
A one-way analysis of variance was performed to determine if there were significant differences between each variable and the two handicap groups (p ≤ 0.05).

**Peak Pelvis Rotation Speed**
The low handicap group had an average peak pelvis rotation speed of 503.21 d/s while the high handicap group had an average peak pelvis rotation speed of

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### Table 1. Golf Specific Warm-up

| Arm Circles | · Raise arms out to side  
| · Start with small circles with hands and gradually increase  
| · Hands should feel light  
| · After 15 seconds switch directions and repeat  
| · Complete each direction twice |

| Overhead Extension | · Grab club just outside shoulder width  
| · Hold club over head with arms extended  
| · Feet shoulder width apart  
| · Bring club down to legs and raise again  
| · Repeat movement for 15 seconds |

| Overhead Sidebend | · Grab club just outside shoulder width  
| · Feet shoulder width apart  
| · Hold club extended overhead  
| · Lean body to one side feel stretch on opposite side  
| · Hold for brief moment and go immediately to other side and repeat  
| · Repeat each side 3 times each |

| Golf Rotations | · Place club over shoulders behind neck  
| · Grab at each end of club  
| · Assume golf posture and rotate upper body back and through  
| · Keep lower body quite still and feel the stretch in mid section  
| · Repeat each side 10 times |

| Modified Good Mornings | · Slightly flexed knees  
| · Grab club and bend at hips  
| · Let arms hang relaxed in front of legs  
| · Stretch hamstrings and lower back by lowering club down legs  
| · Return to starting position and repeat 15 times |

| Partial Squats | · Feet shoulder width apart  
| · Place club in front of you and hold with both hands for balance  
| · Lower body by bending at the knees not hips  
| · Raise back up and repeat 15 times  
| · Keep upper body very erect |

| Side Lunge | · Hold club behind neck, looking straight ahead  
| · Step directly out to one side feeling a little pull up inside of leg  
| · Repeat to the other direction  
| · Alternate directions each time  
| · Repeat 10 times each side |
380.06 d/s (Figure 5 and Table 2). There was a significant difference (p = 0.000) in peak pelvis rotation speed between high handicap and low handicap groups (Figure 4).

Gluteus Maximus Strength
The dynamometer output was given in pounds which was then normalized as % of body weight for each of the subjects. The mean strength results for the low handicap group were: right gluteus maximus = 30.5%, left gluteus maximus = 30.6%. The average strengths of the high handicap group were: right gluteus maximus = 21.9%, left gluteus maximus = 20.7% (Table 2). There was a significant difference (p = 0.000) in gluteus maximus strength between high handicap and low handicap groups.

Gluteus Medius Strength
The mean strength of the low handicap group were: right gluteus medius = 30.5%, left gluteus medius = 30.2%. The average strengths of the high handicap group were: right gluteus medius = 22.6%, left gluteus medius = 22.4% (Table 2). There was a significant difference (p = 0.000) in gluteus medius

| Table 2. Average Peak Pelvis Rotation Speed and Gluteus Maximus and Medius Strengths of Low Handicap and High Handicap Subjects. |
|-----------------------------|-----------------------------|-----------------------------|
| Dependent Variables:        | Low Handicap Group          | High Handicap Group          |
| Peak Pelvis Rotation Speed   | 503.21 d/s                  | 380.06 d/s                  |
| Right Gluteus Maximus       | 30.5%                       | 21.9%                       |
| Strength                    |                             |                             |
| Left Gluteus Maximus        | 30.6%                       | 20.7%                       |
| Strength                    |                             |                             |
| Right Gluteus Medius        | 30.5%                       | 22.6%                       |
| Strength                    |                             |                             |
| Left Gluteus Medius         | 30.2%                       | 22.4%                       |
| Strength                    | d/s = degrees per second; % = strength expressed as a percentage of body weight |
strength between high handicap and low handicap groups.

Correlation Data
A Pearson Product Moment Correlation was performed to see if there was a correlation between peak pelvis rotation speed and strength of the gluteus maximus and/or gluteus medius muscles (Figure 5). A fair correlation existed ($r = .419-.490$) between peak pelvis rotation and strength of the gluteals (Table 3). A fair correlation is considered to be between $r = .25-.5$.

DISCUSSION
The significant difference found in peak pelvis rotation speed between the high and low handicap groups was similar to that found by Cheetham et al indicating a significantly faster peak rotation speed in the low handicap group.3 The average peak pelvis rotation speed of the low handicap group in the current study was 123.15 degrees/second faster than the high handicap. In comparison, the two groups in Cheetham’s study had an average difference of 82.00 degrees/second. A potential explanation for the increased range seen in the current study is that the authors included subjects with no golf experience while Cheetham did not.

The low handicap group (LHC) had significantly stronger gluteus medius and maximus muscles bilaterally. These results have many potential implications. Several authors have investigated the relationship between raw strength versus speed in other rotational sports. Pugh, Koveleski, Heitman, and Parsall compared the grip strength and arm strength of experienced and inexperienced softball players to their underhand pitching speed, and found a correlation between grip strength and throwing speed, $p = / < .05$.12 Similarly, a fair correlation was found in the current study between gluteus strength and peak pelvis rotation speed.

Clearly, raw strength accounts for some of the difference in peak pelvis rotation speed. Other potential factors that may affect this variable include gender, the role of muscle fiber type, and motor learning. The majority of the low handicap group participated in sport specific training for golf in addition to playing an average of four days a week. This being the case, low handicap golfers could have experienced some muscle fiber type adaptations which might play a role in pelvis rotation speed. Gender, as a factor in pelvic rotation speed was not examined.

The role of motor learning in strength development was examined by Selvanayagam, Riek, and Carroll who proposed that the early neural responses to strength training might precede long-term neural adaptation, which ultimately will lead to increased strength.13 The findings from the current study suggest that the LHC group could have more neural responses as compared to the high handicap group (HHC) which in turn would lead to increased motor recruitment both in terms of speed of recruitment and number of fibers stimulated. Ultimately this could lead to increased pelvis speed.

Table 3. Correlation Data between Peak Pelvis Rotation Speed and Strength.

<table>
<thead>
<tr>
<th>Tested Muscle</th>
<th>Pearson Product Moment Correlation*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Gluteus Maximus</td>
<td>$r = 0.419$</td>
</tr>
<tr>
<td>Left Gluteus Maximus</td>
<td>$r = 0.430$</td>
</tr>
<tr>
<td>Right Gluteus Medius</td>
<td>$r = 0.490$</td>
</tr>
<tr>
<td>Left Gluteus Medius</td>
<td>$r = 0.466$</td>
</tr>
</tbody>
</table>

*All correlations are statistically significant at the $p<0.01$ level.
Clinical Implications
Normalizing strength to body weight has the potential implication of carry over into clinical practice. By demonstrating that the LHC group had significantly more strength as a percentage of body weight as compared to the HHC group, it is proposed that gluteus strengthening should be incorporated into golf training and golf injury rehabilitation. A golf specific training program that includes repetition and movement in rotational patterns should be implemented in order to increase speed and efficiency of recruitment and establish motor learning which in turn will increase peak pelvis rotation speed and power during the golf swing. In addition, therapists should incorporate gluteus strengthening when treating injured golfers.

Limitations
A possible limiting factor in this study is true muscle isolation during manual muscle testing. Standardized protocols were used, but compensation could not be ruled out. A key compensatory muscle due to gluteus medius weakness is tensor fascia late recruitment. To strengthen the findings of this study an EMG analysis could have been utilized in order to determine recruitment of the gluteus medius and gluteus maximus and to rule out compensation of other musculature. Another limitation could be that the subjects were asked to wear unfamiliar equipment while performing the swing analysis. Even though five practice swings were given to allow the subject to become familiar with the electromagnetic sensor vest, normal swing mechanics could have been altered due to the equipment. A third limitation is the assumption of handicap for non-golfers. Most subjects recruited for this study had a USGA approved handicap, if subjects were new to golf or did not have enough experience to obtain a handicap, the assumption was made that the subject would have a handicap of 18 or higher.

CONCLUSION
Golfers with a low handicap are more likely to have increased peak pelvis rotation speed as well as increased gluteus maximus and medius strength when compared to high handicap golfers. The relationships between increased peak pelvis rotation and gluteus maximus and medius strength in low handicap golfers have implications in designing golf training and rehabilitation programs. Further research needs to be conducted in order to explore the nature of these implications.

REFERENCES
ABSTRACT

Purpose/Background: The authors speculated that there may be an increased incidence of low back pain (LBP) in NCAA Division III female field hockey (FH) players. FH players may experience LBP for a variety of reasons including trauma from collisions or falls. Excluding these types of direct trauma, FH players may experience LBP due to excessive stress to spinal structures related to the forward flexed posture that predominates in field hockey. The authors speculated that because of the postural stresses inherent to field hockey there may be an increased incidence of LBP in this population. Therefore, the purpose of this study was to survey NCAA Division III female FH players and an age matched control group to determine if field hockey participation results in an increased incidence of LBP. The anticipated finding of an increased incidence of LBP would provide a rationale for the development of prophylactic interventions for this population.

Methods: Subjects: Female NCAA Division III FH players (n=90) ranging in age from 18-24 years old who participated in the 2008 season were surveyed in regards to the incidence of LBP. A female age-matched control group from Misericordia University (n=98) without a history of field hockey participation was also surveyed. Both groups of subjects completed a voluntary pen and paper survey on the incidence of LBP not related to menstruation. Questions included but were not limited to; whether a significant episode of LBP had been experienced, the mechanism or injury, the duration and nature/location of symptoms. Responses from both groups were anonymous and confidential.

Results: There was no difference in the incidence of LBP between the female FH players and the control group (p=0.951). The incidence of LBP was 56% (50/90) in the female FH players and 55% (54/98) in the controls. There was no difference in pain characteristics including pain referral patterns between the 2 groups. However, survey responses revealed a similar mean age of onset of LBP for both groups (16.23 +/- 1.80 years of age for FH players and 16.45 +/- 2.12 years of age for controls).

Conclusions: The data did not support the authors' speculation of a higher incidence of LBP in NCAA Division III female FH players compared to female age-matched controls. This suggests postures associated with field hockey do not appear to significantly increase the incidence of LBP in this population. However, the data revealed that females from both surveyed groups experienced an onset of LBP at a mean age of sixteen.

Key Words: field hockey, low back pain

Level of Evidence: 2b

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This study (Protocol # 23-07-T1) was approved by the Institutional Review Board of Misericordia University.
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INTRODUCTION
Field hockey is a popular sport and played around the world. It is played in many countries and ranks second to soccer as a team sport.\(^1\) Injuries to the lumbar spine as the result of participation in field hockey have been reported in epidemiological studies.\(^1^2^3\) Murtaugh\(^3\) investigated the rates and types of injuries experienced by field hockey players and reported that the low back was the most commonly injured region. Murtaugh reported that 59% of female field hockey players experienced low back pain that they related to playing the sport. Reilly and Seaton\(^4\) reported that 53% of male field hockey athletes reported low back pain. Several authors have linked forward flexion of the spine to the incidence of low back pain.\(^5^6^7\) Sustained forward flexed lumbar postures when coupled with rotation have been demonstrated to be stressful to structures of the lumbar spine.\(^8^9^10^11\) These postures are routinely used by field hockey players when assuming the ready position, pursuing the ball, striking the ball, and defending (Figure 1). The crouched position has been demonstrated to create greater loads to the lumbar spine as compared to normal ambulation and is thought to contribute to low back pain in field hockey players.\(^3^4\)

The stress and strain associated with the flexed spinal postures assumed during field hockey participation could render any number of spinal structures vulnerable to injury resulting in low back pain. Lumbar musculature, tendons, ligaments, joint capsules, the annulus fibrosis of the intervertebral discs, nerve tissues, and osseous structures have been reported to be potential sources of low back pain.\(^5^12\)

The authors contend that the prevalence of flexed lumbar postures that accompany participation in field hockey renders the athletes susceptible to injuries of the lumbar spine at a rate significantly greater than the non-field hockey playing population.

Therefore, the purpose of this research is to describe the incidence of low back pain in a population of NCAA Division III intercollegiate female field hockey players and compare it to the incidence of low back pain in an age-matched cohort. Additionally, the null hypothesis that there would be no significant difference in incidence of back pain between field hockey players and controls, was investigated.

METHODS
Since there may be a higher incidence of low back pain in NCAA Division III intercollegiate female field hockey players as compared to age-matched females, the authors developed a questionnaire that was used to survey athletes and age-matched controls (non-field
hockey players) in order to investigate this possibility (Appendix A). Human subject research approval was obtained from the Institutional Review Board at Misericordia University.

Participants
The field hockey group were NCAA Division III intercollegiate female field hockey players recruited for participation from five NCAA Division III schools (n = 90) and the other group (controls) were a group of age-matched females, recruited from Misericordia University (n = 98). (Table 1)

Questionnaire
The authors developed the pen and paper survey questionnaire utilized in this study (Appendix A). Pen and paper administration was chosen because email survey questionnaires do not often produce the highest response rates for adequate sample size. Prior to utilization a survey questionnaire is recommended to be evaluated for validity. Face validity was determined to exist as prior to utilization in the study the questionnaire was subjected to pilot testing. The pilot representative sample was comprised of 20 non-study participants including 10 female field hockey players and 10 age-matched females. After receiving instructions, the participants in the pilot study read the questions for clarity and provided feedback. Minimal editing was performed in order to improve question clarity. An integral low back pain question was modified and clarified to ensure that low back pain reported on the questionnaire was not associated with menstruation.

Four experts (three doctoral trained physical therapist educators experienced in classification, evaluation, and treatment of patients with low back pain and an experienced MSPT/field hockey coach also reviewed the questionnaire for content validity prior to its utilization. After minor modifications and editing the experts demonstrated agreement regarding the content validity of the questionnaire.

Procedure
Prior to surveying the female field hockey players group, an informational packet was sent to the athletic directors and field hockey coaches of five NCAA Division III schools. The packet contained an informative cover letter, a sample survey, and a consent form. The consent form was completed by all participating institutions prior to the administration of the survey. Control group participants were obtained by responding to a posted notice at Misericordia University explaining the study. All participants were informed that survey information was strictly anonymous, was to be kept confidential, and was to be destroyed after the study was completed. Participants were told that they could in fact turn in a blank form, so those choosing not to participate could not be identified (to ensure blinding). Inclusion criteria were females 18-24 years of age with a self reported episode of low back pain lasting greater than 24 hours that was not associated with menstruation. Additional inclusion criteria included self-reported good general health and no prior history of back surgery. Participation was strictly voluntary. Questionnaire completion was considered assent and evidence of agreement to participate in the study.

RESULTS
Descriptive data was obtained from completed survey questionnaires of both the female field hockey player group and the control group. The descriptive data illustrates similarities in the incidence of low back pain in

<table>
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<tr>
<th>Table 1. Field Hockey and Control Group Demographics.</th>
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<tr>
<td><strong>Female Field Hockey Players</strong></td>
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<tr>
<td>n = 90</td>
</tr>
<tr>
<td>Age (years) 19.22 +/- 1.19</td>
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<td>Range (years) 18-22</td>
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the female field hockey player group compared to the control group. The incidence of low back pain in the control group was 55% (54/98) and 56% (50/90) in the field hockey group respectively. (Table 2)

The data illustrate some additional interesting descriptive findings. (Table 2) The average onset age of low back pain for the controls and the field hockey group was 16.45 +/- 2.12 years old and 16.23 +/- 1.80 years old respectively. Duration of symptoms was also similar for both groups as 85% (46/54) of the controls and 82% (41/50) of the field hockey group had LBP lasting less than 21 days (3 weeks). Additionally, subjects reporting low back pain lasting longer than 1 month were similar in both groups.

The percentage of controls that experienced an episode of low back pain of 1 month or longer was 15% (8/54) compared to 14% (7/50) in the field hockey group. Also, 78% (42/54) of controls compared to 94% (47/50) of the field hockey group reported no trauma as a factor in their low back pain. Both groups included similar numbers of subjects who had low back pain with forward bending. In the control group 57% (31/54) reported pain with forward bending as compared to 50% (25/50) of subjects in the field hockey group. In addition, there were similarities in referred pain (associated pain distal to the buttock) in both groups. Referred pain was reported by 39% (21/54) of the control group compared to 36% (18/50) of field hockey players. Twenty-four percent of

<table>
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<tr>
<th>Table 2. Questionnaire Results for Field Hockey Players and Controls.</th>
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<tr>
<td>Field Hockey Players (n = 90)</td>
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<tr>
<td>Low Back Pain</td>
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<tr>
<td>Onset age (years)</td>
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<tr>
<td>Duration of Symptoms:</td>
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<tr>
<td>1-7 days</td>
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<td>8-14 days</td>
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<td>15-21 days</td>
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<tr>
<td>22-28 days</td>
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<tr>
<td>1-3 months</td>
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<tr>
<td>&gt; 3 months</td>
</tr>
<tr>
<td>Trauma</td>
</tr>
<tr>
<td>No Trauma</td>
</tr>
<tr>
<td>LBP w/ forward bending</td>
</tr>
<tr>
<td>Pain referral:</td>
</tr>
<tr>
<td>Buttock</td>
</tr>
<tr>
<td>Thigh</td>
</tr>
<tr>
<td>Calf</td>
</tr>
<tr>
<td>Foot</td>
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<td>1/18 (6%)</td>
</tr>
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</table>
controls (13/54) reported referred pain distal to the buttock into the thigh, calf and foot regions while 28% (14/50) of the field hockey group reported the same. To summarize, the pain characteristics of the two groups were similar.

The descriptive data above was compiled and subjected to statistical analysis. Levene's test for equality of variances ($p = 0.901$) demonstrated that the variances within groups for pain duration were not significantly different. A 2 tailed t-test ($p = 0.951$) demonstrated that there was no significant difference in the equality of the means of the 2 groups with regard to incidence of pain. (Table 4) or, otherwise stated, there was no significant difference in the incidence of low back pain between the female field hockey player group and the control group. Thus, the null hypothesis that there is no difference between the groups was unable to be rejected. A post hoc power analysis was performed and the power computed to be 92% which exceeds the suggested 80% power value necessary to provide reasonable protection against making a Type II error (stating that there is no significant difference when there is a significant difference). In other words, in the current study there was a 92% probability that the authors would have correctly demonstrated a statistical difference and rejected the null if hypothesis if an actual difference existed between the groups with regard to the incidence of low back pain.

### DISCUSSION

The 56% incidence of low back pain in field hockey players reported by the authors herein is similar to the rates of 59% and 53% reported by Murtaugh, and Reilly and Seaton respectively. However, an increased incidence of low back pain was not present in the female field hockey players in the current study when compared to age-matched controls who were not field hockey players. The incidence of low back pain was similar in both groups, with a 56% (50/90) incidence of low back pain in the field hockey group and a 55% (54/98) incidence of low back pain in the control group. Furthermore, the authors' descriptive statistics revealed that both groups had similarities in regards to the average age of onset of low back pain, in the nature of the pain experienced, in pain distribution, and in pain duration. Based on these findings, a reason for why a difference in the incidence of low back pain was not observed between the groups could be that the flexion stresses on the lumbar spine inherent in field hockey participation (at least at the Division III level) may not be any more stressful than the flexion stresses on the lumbar spine incurred routinely by these populations during normal daily activities.

The authors believe that an important finding of the current study is that over 50% of females in both groups experienced a significant episode of low back pain at a mean age of sixteen. These findings are

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<th>Table 3. Levene's Test for Equality of Variances for Pain Duration (&gt;24 hours) within Groups</th>
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<td>Pain duration &gt; 24 hr</td>
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<td>.015</td>
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<th>Table 4. 2 tailed t-test for Equality of Means of the Groups for Pain Incidence (Pain &gt; 24 hrs).</th>
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<tr>
<td>Pain &gt; 24 hr</td>
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<tr>
<td>t</td>
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<tr>
<td>-.062</td>
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<tr>
<td>Equal variances not assumed</td>
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<td>-.062</td>
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similar to those reported by Salminen\textsuperscript{15} who reported that half of all children between the ages of 15-18 noted a history of low back pain regardless of athletic participation. In a study on the natural history of low back pain in adolescents Burton et al\textsuperscript{16} reported similar findings with an incidence of low back pain onset in both boys and girls by the age of fifteen. Burton reported that higher prevalence of low back pain was associated with more strenuous sport activities. Burton also noted the incidence rate for low back pain in adolescents increased with age and by 15+ years of age 50% of adolescents in the United Kingdom experienced back pain.

Based on the data from previous studies the authors note that low back pain seems to occur frequently (incidence of 50%) in the general youthful female population (15-18 years of age). The authors’ data suggests a slightly greater incidence of low back pain (55%) than reported or anticipated in the general youthful female population. Field hockey participation at 15-18 years of age is common to those matriculating to NCAA Division III participation and consequently why a question regarding age of onset was relevant to the questionnaire used in the authors’ study. In fact, Sherker and Cassell\textsuperscript{1} reported that data from Australian emergency departments showed that field hockey players aged between 10 and 19 years account for 50% of all hockey injuries. The authors of this study are of the opinion that a greater than 50% incidence of low back pain in females in this age group is high, regardless of field hockey participation, and should be of concern especially if it may relate to a lifetime of low back pain. This concern should spurn questions of what factors may contribute to the high incidence of low back pain in this youthful population both of athletes and non-athletes alike. Previous studies have investigated such possible contributing factors. Harvey et al\textsuperscript{17} reported that low back pain in adolescents may be due to growth spurts combined with increased activity levels. Harvey mentioned additional factors that may predispose adolescents to low back pain including inadequate strength of back extensor and abdominal musculature, as well as inflexibility of the lumbar spine.

In a study performed by Feldman et al,\textsuperscript{18} rapid growth spurts, hamstring tightness, working at a job during the school year, smoking, and poor mental health were all found to be associated with low back pain in adolescents. Additional studies mentioned smoking to be associated with low back pain in adolescents.\textsuperscript{19,20} Auvinen et al\textsuperscript{21} investigated physical activity and its association to low back pain in adolescents and reported that male and female adolescents who participated in greater than 6 hours of brisk physical activity participation per week frequently experienced low back pain. A survey study performed by Hakala et al\textsuperscript{22} showed that 14-16 year olds with a daily use of computers exceeding 5 hours experienced and reported low back pain. Sjölie\textsuperscript{23} surveyed 88 adolescents (mean age 14.7) and found that a higher than mean body mass index and less than mean hamstring flexibility were associated with low back pain. Another survey study conducted by Sjölie\textsuperscript{24} found that poor well-being and specifically poor self perceived fitness were associated with low back pain in adolescents.

As noted above, there are many factors that may contribute to a high incidence of low back pain in the general youthful population, a number of which are mechanical or postural in origin and therefore potentially amenable to intervention. Based on these findings future research could focus on identifying the most significant causes and appropriate intervention strategies to minimize the incidence of low back pain in the general female youthful population. This is opposed to the specific focus on low back pain in female field hockey players as was the authors’ original intent.

When comparing the incidence and characteristics of low back pain in the 2 groups the authors would like to note some limitations of the current study. A concern of the authors is that some of the field hockey players were involved in pre-season or in-season back/core muscle strengthening programs. Also, some of the controls were engaged in sports, general exercise, and or exercise programs that may have targeted the back/core musculature. Although exercise and sports involvement were items on the questionnaire developed for and used during the current research, the responses were not of a consistent nature. The varying involvement in exercise and other sports activities may have had an influence on the incidence of low back pain in the two groups.

Another factor that may have influenced the results of the current study was the access to different health care professionals with differing interventions for
low back pain. For example the field hockey group may have had ready access to a team physician and or an athletic trainer for intervention whereas the controls most likely did not have this access and may have managed their condition independently. Varied interventions may have included diagnostic testing, medication and modality treatment, as well as different manual therapy and exercise. Each of these factors could have influenced the severity and duration of low back pain reported by the groups.

CONCLUSION
At the onset of this study the authors speculated that there would be an increased incidence of low back pain in NCAA Division III female field hockey players as compared to non-participating age matched female controls. No statistically significant differences in the incidence of low back pain or pain characteristics were found between the two groups. However, both subjects and controls presented with a high incidence of low back pain (>50%) with an onset of low back pain at a mean age of approximately sixteen.

REFERENCES
Appendix A: Questionnaire Used

Questionnaire Directions:
This is an anonymous questionnaire. No one including those doing the study will know who you are. Please answer each question as best as you can. If you are not sure, estimate as best as you can.

Age:

Have you ever experienced low back pain lasting more than 24 hours and not associated with menstruation?
Yes No

If yes, how old were you when you first experienced low back pain?
__________ years old

How long did the low back pain last?
1-7 days 8-14 days 15-21 days 22-28 days 1-3 months > 3 months

Was there a specific trauma involved?
Yes No

If yes, can you describe the trauma?
________________________________________________________________________
________________________________________________________________________

Where any imaging studies performed (x-ray, CT scan, MRI)?
Yes No

If yes, what were the findings?_____________________________________

Did your pain limit your ability to bend?
Yes No

Did you experience any pain in your buttock, thigh, calf or foot that appeared to be associated with the low back pain?
Yes No

If yes, what was the farthest point the pain was experienced down your leg.
Buttock Thigh Calf Foot

Did you ever experience any sensory changes in your back or leg such as numbness, tingling, or hot or cold feelings?
Yes No

If yes, what was the furthest the change in sensation was experienced down your leg?
Buttock Thigh Calf Foot

Have you ever felt that you experienced weakness in either leg that was associated with you back pain?
Yes No
Do you play any sports?  Yes  No

If yes, what sport or sports? And at what level (recreational, intramurals, club or NCAA)

Sport _____________________________  Level _______________________
Sport _____________________________  Level _______________________
Sport _____________________________  Level _______________________
If you do not play Field Hockey, stop here. Thank you for your participation.

Answer this section only if you play Field Hockey on a College or University NCAA sanctioned team.

What NCAA level do you play Field Hockey?  (1, 2, or 3) ____________

Number of years you have played field hockey: ____________years

Position you predominately play:  Forward        Midfield        Defense

Have you ever injured your low back while playing field hockey?  
Yes  No

If yes, do you recall how it occurred?
________________________________________________________________________
________________________________________________________________________

Were you ever instructed on how to stand when the action on the field was away from you? (Ready position)  
Yes  No

If yes, please describe the position:

If yes, did you experience low back pain as a result of using this position?

Did the pain affect your ability to play the sport at the level that you expected to play?
Yes  No

Did you ever miss time from either practice or games because of the pain?
Yes  No

If yes, estimate the longest you were ever out for?

        Days        Weeks        Months

During the preseason do you do any exercise for you back muscles or abdominal muscles such as “core exercises or Pilates”?
Yes  No
During the regular season do you do any exercise for your back muscles or abdominal muscles such as “core exercises or Pilates”?
Yes  No

If yes, how often do you do the exercises?_______

Do you believe field hockey is strenuous on your low back?
Yes  No

**Thank you for your participation in this study.**
ABSTRACT

**Purpose/Aim:** This study investigated the intrarater reliability and concurrent validity of active shoulder mobility measurements using a digital inclinometer and goniometer.

**Materials/Methods:** Two investigators used a goniometer and digital inclinometer to measure shoulder flexion, abduction, internal and external rotation on 30 asymptomatic participants in a blinded repeated measures design.

**Results:** Excellent intrarater reliability was present with Intraclass Correlation Coefficients (ICC- 3,k) for goniometry $\geq 0.94$ and digital inclinometry $\geq 0.95$. The concurrent validity between goniometry and digital inclinometry was good with ICC (3,k) values of $\geq 0.85$. The 95% limits of agreement suggest that the difference between these two measurement instruments can be expected to range from $2^\circ$ to $20^\circ$.

**Conclusions:** The results cautiously support the interchangeable use of goniometry and digital inclinometer for measuring shoulder mobility measurements. Although reliable, clinicians should consider the 95% limits of agreement when using these instruments interchangeably as clinically significant differences are likely to be present.

**Level of evidence:** 2b

**Key Words:** Goniometry, inclinometry, reliability, shoulder, validity
INTRODUCTION
The assessment of mobility is an integral component of a physical examination. The examination of joint integrity and mobility is necessary in order to select appropriate physical therapy interventions. Recognizing impairments in joint mobility may assist clinicians in making diagnoses, measuring improvements or deteriorations in mobility, and in determining functional limitations. Therefore, it is essential for clinicians to have reliable and valid measurement instruments in order to objectively monitor disease progression, outcomes, and mobility impairments.

The examination of shoulder mobility may be accomplished using a number of instruments including: visual observation, goniometry, linear measures, and inclinometry. The method and type of assessment will vary among clinicians and institutions based on factors such as time, educational inclination of the clinician, availability of equipment, and the specific movement or tissue being assessed. Goniometry has been used widely due to its portability and low cost. However, a limitation of goniometry is that it requires the clinician to use both hands, making stabilization of the extremity more difficult, and thus increasing the risk of error in reading the instrument. Inclinometry is another practical alternative that incorporates the use of constant gravity as a reference point to assess joint mobility. Digital inclinometers are portable, lightweight, and require training similar to that of goniometry. However, a disadvantage of digital inclinometry may lie in the fact that it is more costly than conventional goniometers, and requires the examiner to establish the zero point of the digital inclinometer accurately and consistently prior to use in order to minimize the risk of measurement errors.

A recent literature review of shoulder mobility measurements identified comparable use of goniometry and inclinometry among published research investigations; however, no study existed to compare the concurrent validity of goniometric and inclinometric measurements of shoulder mobility, further investigation is essential in order to provide clinicians and researchers with the necessary information needed to make clinical decisions regarding their interchangeability. Therefore, the primary purpose of this study was to investigate the concurrent validity of digital inclinometry and goniometry for measuring active shoulder abduction, flexion, internal and external rotation. Additionally, we sought to investigate the intrarater reliability for both instruments.

DESIGN
Participants
Thirty asymptomatic adult participants, 9 males and 21 females, were recruited from a local university setting. Participants who met study requirements were provided with an informed consent document approved by the Institutional Review Board at Nova Southeastern University and all questions were answered to their satisfaction prior to commencing data collection. Participants completed a questionnaire to report age, height, body mass, and arm dominance. Exclusion criteria consisted of reported cervical spine or upper extremity pain at the time of data collection or recent shoulder surgery on the dominant arm for which the subject was still receiving care. The mean and standard deviation (SD) for the participants’ age, body mass, and height were 26 (4.2) years, 70 (11.3) kg, and 170 (8.1) cm respectively. Testing was conducted on the dominant arm. The right arm was dominant in 26 of the 30 participants.

Instruments
A standard plinth and ACUMAR™ digital inclinometer, (Model ACU 360) Lafayette Instrument Company (Lafayette, Indiana) was used for all inclinometric measurements (Figure 1). The manufacturer specifications indicate that this instrument is capable of measuring a range up to 180° with an accuracy of ±1°. A 24 inch bubble level, (model 7724-0, Johnson Level & Tool; Mequon, Wisconsin) was used to zero the inclinometer prior to measurements. A 12-inch plastic BASELINE® goniometer, (Model 12-1000)
Fabrication Enterprises (White Plains, New York) was used for all goniometric measurements (Figure 2).

**Procedures**

Following completion of paperwork and consent, individuals who agreed to participate were brought into a private testing laboratory where they performed a standardized warm-up supervised by the raters who were all third year doctoral physical therapy students. The warm-up required approximately 2 minutes to complete and consisted of ten pendulums both clockwise and counterclockwise as well as ten repetitions of standing shoulder blade squeezes. Each participant was required to perform the same warm-up for consistency; however, to the authors' knowledge there is no benefit or detriment to performing the warm-up.

Following the warm-up, all participants completed the measurements with their dominant arm in an intrasession design. Rater A performed the goniometric measurements and Rater B inclinometric measurements. Prior to taking each of the 4 measurements (flexion, abduction, ER and IR), Rater B passively moved the participant’s dominant arm through one repetition in the desired plane up to the point of an end-feel. The purpose of the passive trial repetition was to familiarize the participant with the requested motion. Following the passive trial participants performed each of the four active range of motion (AROM) actions in consecutive order (flexion, abduction, ER and IR) with 1-minute rest intervals between consecutive measurements. For each active repetition, participants were requested to move their arm to end-range and maintain the position while the angle was recorded with the goniometer and inclinometer. Once the measurement was recorded, participants returned their arm to a neutral zero-degree position and the measurement was repeated. Each measurement was obtained twice with the goniometer and twice with the inclinometer before proceeding to the next movement plane. The mean value of the two measurements from each instrument was used for analysis. The raters were blinded to the results, as an independent third person (Rater C) with similar experience in goniometry

![Figure 1. ACUMAR™ Digital Inclinometer, (Model ACU 360) Lafayette Instrument Company: Lafayette, Indiana.](image1)

![Figure 2. Standard BASELINE® 12-inch plastic goniometer, (Model 12-1000) Fabrication Enterprises, Inc: White Plains, New York.](image2)
and inclinometry recorded all data. Verbal cues were provided strictly as necessary to ensure proper form during the measurement and to ensure movement was performed to the available end-range.

The procedures for measuring active flexion, abduction, external rotation, and internal rotation followed guidelines established by Clarkson and that have previously been reported in the literature to have good intrarater reliability with intraclass correlation coefficients (ICC) of ≥0.85.8

Flexion-AROM was assessed with the participant seated upright in a high back chair and a cloth gait belt secured around their waist (at the level of the umbilicus) and back of the chair to limit trunk compensation. The arm was actively elevated in a strict sagittal plane with the palm down to the participants' end-range ability at which time the measurement was recorded. For inclinometry the instrument was placed on the distal upper arm proximal to the elbow and distal to the glenohumeral joint. The goniometric measurement was taken with the fulcrum placed inferior and lateral to the acromion process, the stable arm parallel to the trunk and the moving arm parallel to the longitudinal axis of the humerus.

Abduction-AROM was measured in the seated chair position, as in flexion, with the trunk upright. The arm was actively elevated in the strict coronal plane with the thumb pointed up toward the ceiling to allow the required external rotation necessary to avoid impingement of the greater tuberosity on the acromion process.9 Once active end-range was achieved the measurements were documented. For inclinometry, the instrument was placed on the distal arm proximal to the elbow and distal to the glenohumeral joint. The goniometric measurement was taken with the fulcrum placed at the midpoint of the posterior aspect of the glenohumeral joint, the stable arm parallel to the floor and the moving arm parallel with the forearm.

External rotation-AROM was tested in the supine position with the hips and knees flexed to approximately 45 degrees. The tested arm was supported on the table in 90 degrees of abduction, elbow flexed to 90 degrees, and the wrist in neutral. A towel roll was placed under the humerus to ensure neutral horizontal positioning; which required the humerus to be level to the acromion process based on visual inspection. Once positioned, the participant was asked to rotate their arm back into external rotation to their end available range without discomfort. The participant was instructed not to lift their lower back during this measurement. Once active end-range was achieved the measurement was recorded. The inclinometer was placed on the distal forearm just proximal to the wrist for recording the measurement whereas the goniometric measurement was taken with the stable arm parallel to the floor and the moving arm parallel with the forearm.

Internal rotation-AROM was measured in the prone position with the tested arm supported on the table in 90 degrees of abduction, the forearm flexed to 90 degrees, and the wrist in neutral. A towel roll was placed directly under the arm to ensure neutral horizontal positioning and to provide stabilization. The participant was instructed to internally rotate their arm while maintaining the 90 degree abducted position. The tester carefully monitored participants to avoid compensatory scapular movement through verbal cues. Manual cues were provided as necessary if the participant did not maintain the required testing position on the first attempt. Manual cues were required for 4 participants to keep their arm in the 90-degree abducted position; however, the prone position was chosen as it did prevent anterior tilting of the scapula at end-range. Once active end-range was achieved the measurement was recorded. The inclinometer was placed on the distal forearm just proximal to the wrist for recording the measurement, whereas goniometric measurements were taken with the stable arm parallel to the floor and the moving arm parallel with the forearm.

The measurements required approximately 30-minutes from the initiation of the warm-up to completion. Raters remained blinded to both their results as well as the other rater's results throughout the investigation.

STATISTICAL METHODS

Data analysis was performed with SPSS version 15.0 for Windows. Descriptive data including mean measurement angles with standard deviations (SD) were calculated for each session. The intrarater reliability was determined by the ICC Model 3, k. The mean value from each testing session was used for the analysis. Model 3, k was used for the intrarater analysis because the specific rater was the only
Interpretation of ICC values was based on guidelines offered by Portney and Watkins,10 where a value above 0.75 was classified as good reliability. ICC values may be influenced by intersubject variability of scores, because a large ICC may be reported despite poor trial-to-trial consistency if the intersubject variability is too high.10,12 The standard error of measurement (SEM) is not affected by intersubject variability.12 Therefore, SEM was reported in conjunction with the ICC’s using the formula: SEM = SD/ sqrt(1-r).10 An ICC Model 3, k was used in the concurrent reliability analysis to determine if both methods of measurement analysis produced comparable results. ICC value interpretations were based on the aforementioned guidelines established by Portney and Watkins.10 The 95% limits of agreement (LOA) were calculated using the formula: 95% limits of agreement = mean difference +/- 2SD.10

RESULTS
Descriptive data, including the mean and SD for each of the four measurements are presented in Table 1. Intrarater analysis suggested excellent reliability for all measurements with both instruments ranging from, ICC (3,k) =0.94-0.98. There was a trend for higher reliability with the inclinometric measurements when compared to goniometry. Measurement data from the intrarater reliability analysis including the ICC, 95% CI and SEM are presented in Table 2. The concurrent validity between goniometry and digital inclinometry measurements are presented in Table 3. When comparing the mean end-range angles for the instruments a trend existed for lower goniometric values of flexion, abduction and external rotation compared to inclinometry. The mean goniometric value of internal rotation, however, was greater than the mean inclinometric value. In regards to agreement the 95% LOA suggests that goniometry may range from being 20° less than to 5° greater than inclinometry when measuring flexion. The 95% LOA suggests that goniometric abduction may range from 17° less

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<th>Table 1. Descriptive Measurement Data.</th>
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<tr>
<td><strong>Flexion</strong></td>
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<tr>
<td><strong>Abduction</strong></td>
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<tr>
<td><strong>Ext. Rotation</strong></td>
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<tr>
<td><strong>Int. Rotation</strong></td>
</tr>
<tr>
<td>Goniometer</td>
</tr>
<tr>
<td>156(9)</td>
</tr>
<tr>
<td>161(11)</td>
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<tr>
<td>92(10)</td>
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<tr>
<td>48(10)</td>
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<tr>
<td>Inclinometer</td>
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<td>164(9)</td>
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<td>162(11)</td>
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<tr>
<td>100(11)</td>
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<td>43(10)</td>
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<td>SD= standard deviation; Ext= external; Int= internal.</td>
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<tr>
<th>Table 2. Intrarater Reliability of Goniometer and Inclinometer.</th>
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<tr>
<td><strong>Goniometer</strong></td>
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<td><strong>Inclinometer</strong></td>
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<tr>
<td><strong>Flexion</strong></td>
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<tr>
<td><strong>Abduction</strong></td>
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<tr>
<td><strong>Ext. Rotation</strong></td>
</tr>
<tr>
<td><strong>Int. Rotation</strong></td>
</tr>
<tr>
<td>ICC (95% CI) SEM*</td>
</tr>
<tr>
<td>0.95(0.89-0.98) 2*</td>
</tr>
<tr>
<td>0.97(0.94-0.99) 2*</td>
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<tr>
<td>0.94(0.87-0.97) 3*</td>
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<tr>
<td>0.95(0.89-0.98) 2*</td>
</tr>
<tr>
<td>ICC= intraclass coefficient; SEM= standard error of measurement rounded to nearest degree; CI=Confidence interval; Ext= external; Int= internal</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Table 3. Concurrent Reliability of Goniometry and Digital Inclinometry.</th>
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<tr>
<td><strong>Measurement</strong></td>
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<tr>
<td>Flexion</td>
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<tr>
<td>Abduction</td>
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<tr>
<td>Ext. Rotation</td>
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<tr>
<td>Int. Rotation</td>
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<tr>
<td>ICC= Intraclass Correlation Coefficient; CI= Confidence interval; Ext= external; Int= internal</td>
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</table>
than to 14° greater than inclinometry. Goniometric external rotation may range from 2-16° less than inclinometry, whereas internal rotation measurements ranged from 3-15° greater than inclinometry.

**DISCUSSION**

When adhering to the procedures outlined in this investigation, measurements taken using both the inclinometer and goniometer possessed good intrarater reliability. The reliability results are comparable to previous research which has reported the good to excellent intrarater reliability when utilizing similar measurement procedures.8

In regards to concurrent validity, measurements with a digital inclinometer were found to be comparable to those taken with the standard 12-inch plastic goniometer with ICC values ≥ 0.85. Also, there was a trend for inclinometric measurements being greater than goniometry for flexion, abduction and external rotation. In contrast, goniometric internal rotation measurements had a greater mean measurement angle than inclinometry. The mean differences in measurements between the instruments were the greatest for external rotation and flexion and had the narrowest range for abduction. There was no identifiable systematic error in technique that could explain the differences. One might surmise that Rater A (who took all goniometric measurements) was biased toward lower angles, however, internal rotation was higher from Rater A which challenges that assumption. Furthermore, the landmarks for measurements are different which may produce different end-ranges and should be of concern to clinicians. Unfortunately, no studies have established the validity of these instruments concurrently with radiography to determine which one might offer a more valid estimate of mobility. Clinicians and researchers should recognize that the difference between these two measurement instruments can be expected to vary by 2°- 20° with differences dependent upon the movement being measured. From a clinical perspective this cannot be overlooked as the upper range of disagreement at 20 degrees may lead to differences in both diagnosis and the plan of care particularly as related to interventions designed to improve mobility.

Only two previous studies have investigated the concurrent validity of similar instruments for measuring shoulder function. One study investigated the concurrent validity of scapular plane elevation using similar instruments to this investigation.13 In the aforementioned study the concurrent validity was good with an ICC value of 0.94 and the 95% LOA suggesting that the difference between these two measurement instruments can be expected to vary by up to +/- 11°. Another study investigated the concurrent validity of goniometry and a construction grade digital level and reported ICC values of non-involved (asymptomatic) to involved (symptomatic) shoulder motions of flexion, ER and IR.14 In the aforementioned study the concurrent validity was reported to range from ICC = 0.71-0.98 for both non-involved and symptomatic shoulders. For shoulder flexion the ICC ranged from 0.91-0.95 for the involved shoulder compared to 0.81-0.86 for the uninvolved. ER ranged from 0.91-0.96 (involved) to 0.71-0.94 (uninvolved) whereas IR ranged from 0.82-0.96 (involved) to 0.83-0.93 (uninvolved).14 While the aforementioned study offers insight into the interchangeability, the construction-grade digital level may not be comparable to traditional inclinometers such as the one used in this investigation.

This study was the first to analyze the concurrent validity of goniometric and digital inclinometric measurements of shoulder mobility. Due to the lack of research in this area, a comparison between the current study and previous research cannot be made. However, this study does set the groundwork for further research in this area in order to evaluate the interchangeability of goniometric and digital inclinometric measurements.

**LIMITATIONS AND FUTURE RESEARCH**

When interpreting the reliability values in our investigation, one must recognize that the consistency of AROM in individuals with healthy shoulders may not correlate with those who have shoulder pathology. Triffitt et al15 assessed the reproducibility limits of inclinometric shoulder abduction and external rotation in both symptomatic and asymptomatic subjects. Asymptomatic subjects had a difference ranging from 24 to 33° for all measurements as compared to 24 to 41° in symptomatic subjects, suggesting a greater variance among those with a painful shoulder. While the authors of the current study cannot state with certainty that this would be the case with all testers and procedures it is an issue requiring consideration.
Additionally, when studying a symptomatic population, the ability of an individual to achieve and maintain their arm in a specific plane may be compromised secondary to restrictions in joint mobility and/or pain. Moreover, this investigation required participants to hold their end-range for a time period that allowed two measurements (inclinometry and goniometry) to be performed which may not have been possible in a symptomatic cohort. Lastly, the participants in this investigation consisted of a young, college-aged population (mean age = 26). The average age of individuals seen in the clinical setting is 44 years. Therefore, the current results may not necessarily be generalized to a sub-group with increasing or decreasing age.

When comparing instruments such as goniometry and inclinometry it is important to consider limitations to both instruments. The inclinometer uses a fixed vertical reference point realized by gravity, thus is stable provided the zero point is accurately calibrated and established. Traditional goniometry requires visualization of the vertical reference point, which may compromise measurement reproducibility. Another issue that warrants discussion is the potential effect of body types (ectomorphs versus endomorphs and mesomorphs) on digital inclinometer measurements. The inclinometer measurements of shoulder flexion and abduction were taken at the midline of the humerus on the superior portion of the biceps brachii. Ectomorphic body types tend to have a linear frame with sparse muscular development whereas, mesomorphs and endomorphs have a greater amount of tissue surrounding their frame. Digital inclinometer measurements may differ from goniometric measurements due to the differences in tissue mass.

Lastly, the mean values of flexion and abduction obtained in this study may be less than that obtained in a clinical setting or reported in examination textbooks. The difference in values is most likely the result of adherence to strict measurement planes in this investigation. Following strict measurement protocols prevents compensatory movements that may allow higher ranges to be measured. Although the raters had limited clinical experience they were intentionally following a research protocol that was practiced thus experience does not appear to have had an effect on the mobility values.

CONCLUSION
This investigation is the first of its kind to evaluate the reliability and concurrent validity of digital inclinometric and goniometric measurements of active shoulder flexion, abduction, external and internal rotation. When used with the measurement procedures outlined in this investigation, both techniques are reliable, as evidenced by reliability coefficients that exceed 0.90 (the threshold recommended for making clinical decisions). Good concurrent validity statistics were produced; however, one should recognize the potential ranges of disagreement between the two measurement instruments used in this study. When monitoring or comparing active shoulder mobility measurements both researchers and clinicians should consider using similar instruments.

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ABSTRACT

Purpose/Background: Pain can adversely affect muscle functioning by inhibiting muscle contractions. Delayed onset muscle soreness was used as a tool to ascertain whether a topical menthol-based analgesic or ice was more effective at reducing pain and permitting greater muscular voluntary and evoked force.

Methods: Sixteen subjects were randomized to receive either a topical gel containing 3.5% menthol or topical application of ice to the non-dominant elbow flexors two days following the performance of an exercise designed to induce muscle soreness. Two days later, DOMS discomfort was treated with a menthol based analgesic or ice. Maximum voluntary contractions and evoked tetanic contractions of the non-dominant elbow flexors were measured at baseline prior to inducing muscle soreness (T1), two days following inducing DOMS after 20 (T2), 25 (T3) and 35 (T4) minutes of either menthol gel or ice therapy. Pain perception using a 10-point visual analog scale was also measured at these four data collection points. Treatment analysis included a 2 way repeated measures ANOVA ($2 \times 4$).

Results: Delayed onset muscle soreness decreased ($p = 0.04$) voluntary force 17.1% at T2 with no treatment effect. Tetanic force was 116.9% higher ($p<0.05$) with the topical analgesic than ice. Pain perception at T2 was significantly ($p=0.02$) less with the topical analgesic versus ice.

Conclusions: Compared to ice, the topical menthol-based analgesic decreased perceived discomfort to a greater extent and permitted greater tetanic forces to be produced.

Key Words: analgesia, cryotherapy, delayed onset muscle soreness, menthol, self-reported pain

Level of Evidence: Level 2b
INTRODUCTION

Delayed onset muscle soreness (DOMS) is a common consequence of unaccustomed exercise or overtraining especially with the inclusion of extensive eccentric contractions. DOMS is commonly observed with athletes, weight lifters, and is frequently observed among recreational athletes. The presence of DOMS inhibits muscle activity or motor performance for up to several days following the initiating event. One of the major symptoms of DOMS is pain which can cause inhibition of force production of the involved muscle.

Various methods of ice application including cold water immersion have been used to treat DOMS with inconclusive results. Isabell et al found no clinically significant effect of ice massage on DOMS. Connolly et al countered in their review that cold water immersion has been shown to be effective in providing some relief of DOMS. Although ice is commonly used to alleviate pain the evidence for its effectiveness for relieving DOMS is contradictory.

Topically applied gels, which contain menthol, are also used as analgesics. Topically applied menthol gels result in a cooling sensation and are reported to act as a counterirritant to reduce the sensation of pain. Menthol generates feelings of cold via the transient receptor potential family of ion channels or (TRP’s). TRP’s are found throughout the body, but TRPM8 are found mainly within thermosensitive neurons, which in addition to responding to reductions in temperature are also particularly sensitive to menthol. TRPM8 serves as a neuronal sensor of cold temperatures and is essential for receiving input regarding innocuous cool and noxious cold sensations. Utilization of calcium imaging techniques has demonstrated that upon the application of menthol to cloned TRPM8 cells, a heavy intracellular influx of calcium ions caused neural depolarization due to the opening of non-selective calcium permeable cation channels. This increase in sensitization of the thermosensitive neurons is what leads to the perceptions of coolness with topical menthol application. Stimulation of these thermosensitive neurons is also associated with an analgesic effect. Afferent thermosensitive neurons which are stimulated by moderate cooling or the application of menthol have been found to have an inhibitory effect on the nociceptive afferent neurons and on the dorsal-horn neurons which conduct pain impulses to the thalamus. This analgesic effect of menthol was demonstrated in vitro by Haeseler et al when studying the effect of an electrical stimulus applied to human skeletal muscle tissue after the tissue was exposed to menthol. At various menthol application strengths, inactivated sodium channels were measured to determine the effect on depolarization. It was demonstrated that the menthol blocked the alpha sub-unit of voltage gated sodium channels, therefore causing hyperpolarization of the nervous membrane and a block in the signal of pain transduction. This study demonstrated that the application of menthol could have an analgesic effect through exerting an inhibitory gate control over nociceptive inputs. There are no studies, to date, which have compared the analgesic effects of topical applications of ice with menthol-based gel on DOMS symptoms.

Therefore, the purpose of this study was to compare applications of topical menthol with ice on pain, maximum voluntary contraction and evoked tetanic force during DOMS. It was hypothesized that the menthol based topical analgesic would be more effective than ice in alleviating DOMS-related symptoms (pain and force reductions). Thus menthol’s analgesic effect on pain would improve strength output.

METHODS

Participants

Sixteen (Menthol [Biofreeze®] group: 24.2 ± 2.1 yrs, 181.6 ± 4.5 cm, 76.1 ± 10.3 kg; Ice group: 22.8 ± 1.8 yrs, 178.3 ± 3.9 cm, 73.9 ± 7.5 kg) healthy, physically active subjects (performed regular physical activity a minimum of three per week) including 12 males and 4 females from Memorial University of Newfoundland were randomized to receive either a topical gel containing 3.5% menthol or a topical application of ice (using an ice bag) to their non-dominant elbow flexors two days following performing an exercise designed to induce DOMS in this muscle group. No participant had any previous history of cardiopulmonary, neurological, cognitive problems, sensory deficits, cold intolerance, or hypersensitivity. The upper limbs were visually checked to ensure the absence of any skin wounds, lesions and rashes. All subjects were given verbal information on the procedure of study as well as a brief overview of the purpose of the research. A Physical
Activity Readiness Questionnaire (PAR-Q)\textsuperscript{20} was given to every subject to ensure the subjects’ health status was sufficient to participate in physical activity. Using a random allocation method, subjects were divided into two groups; menthol based topical analgesic and ice intervention groups. All subjects read and signed a written informed consent document before participation that was approved by The Human Investigation Committee of Memorial University of Newfoundland.

**Delayed Onset Muscle Soreness (DOMS) Exercise Intervention**

Following completion of the informed consent process, the PAR-Q and being assigned to an experimental group all subjects were instructed to sit with their upper arm supported on an inclined padded bench and hold a free weight dumbbell to provide the resistance in their non-dominant hand. The lower arm and dumbbell hung freely over the edge of the bench. The one repetition maximum (1 RM) was determined for the elbow flexors of non-dominant arm (the left arm for all subjects in this experiment)\textsuperscript{21} using the procedure described by Robbins et al.\textsuperscript{22,23} According to this procedure an additional 10% was added to the 1 RM resistance, in order to successfully induce DOMS. Initially, the investigators helped raise the resistance to full elbow flexion with minimal assistance from the subject. The subject then performed an eccentric contraction to return the weight to starting position\textsuperscript{2} over a 5s duration. Each subject performed ten sets of 10 repetitions of this eccentric exercise of the non-dominant arm. If a subject was not able to control the lowering of the weight over the 5s duration the resistance was reduced by 2.5 kg to ensure the completion of 10 sets. A one-minute recovery period was provided between each set. DOMS was induced in this study as an experimental tool to induce musculotendinous pain.

**Menthol Based Topical Analgesic and Ice Treatment Interventions**

The treatment interventions were applied approximately 48 hours or two days following the DOMS inducing session. For the menthol gel group, 2ml of Biofreeze\textsuperscript{®}, a gel containing 3.5% menthol was applied topically over the belly of the biceps brachii. The mode of application did not involve substantial force, pressure or rubbing and thus any reflex activation would not have been expected. This dose of Biofreeze\textsuperscript{®}, was based upon the estimate that the average skin surface area over the biceps brachii was approximately 400 cm\textsuperscript{2} and the recommended dosage of Biofreeze\textsuperscript{®} of 1 ml per 200 cm\textsuperscript{2}.\textsuperscript{24} Twenty minutes (T2) following the application of the menthol gel each participant completed an assessment of their MVC, evoked tetanic force and perceptions of pain. These assessments were repeated at 25 (T3) and 35 (T4) minutes following the application of the menthol gel. Whereas the effect of menthol-induced reduced vascular conductance has been reported to endure for at least 20 min,\textsuperscript{24,25} the subjective cooling effect has been reported to last up to 70 min in some subjects (mean 32 min).\textsuperscript{9} The protocol for application of the ice was similar to that of the menthol gel. Subjects who were randomized into this group underwent the same baseline assessment of their MVC evoked tetanic force and their perceptions of pain (T1) prior to inducement of DOMS. Then these individuals reported to the laboratory approximately 48 hours (or 2 days) following the DOMs inducement protocol. At this time .5kg of crushed ice in a plastic bag was placed over the non-dominant biceps brachii for 20 minutes and then removed.\textsuperscript{26,27} Assessments of MVC, evoked tetanic force and their perceptions of pain were repeated immediately following the removal of the ice (T2), and at 25 (T3) and 35 (T4) minutes following initial application of the ice.

One researcher performed all the intervention applications, while another researcher was blinded to the group allocation during testing. Anonymous codes were assigned for analysis so that only the third researcher who did not perform the data analysis was cognizant of group allocation.

**Dependent Variables**

Measurements of voluntary (elbow flexor isometric MVC) and evoked (tetanic force) contractile properties were randomly allocated. While subjects sat upright in a chair, the left shoulder and elbow were flexed at 90\textdegree with the forearm vertical and fully supinated. The upper arm was fastened to the chair via an adjustable strap to avoid movement during voluntary force measurements. Both forearm and wrist of the testing arm were rested on a padded support and secured to a
strap attached to a high tension wire to a Wheatstone bridge configuration strain gauge (Omega Engineering Inc., LCCA 250, Don Mills, Ontario, Canada), amplified (Biopac Systems Inc., Holliston, Massachusetts; DA 100 and analog to digital converter MP100WSW) and monitored on computer (Dell Inspiron 6000, St. John’s, Newfoundland, Canada). All data were stored on a computer at a sampling rate of 2000 Hz. Data were recorded and analyzed with a commercially designed software program (AcqKnowledge III, Biopac Systems Inc., Holliston, Massachusetts).

To assess peripheral (muscle) force changes associated with DOMS and the treatment interventions, bipolar surface stimulating electrodes were secured to the proximal anterior portion of the forearm flexors and deltidoid-biceps brachii intersection. Similar to previous research from this laboratory stimulating electrodes, 4–5 cm in width were constructed in the laboratory from aluminum foil, paper coated with conduction gel (Signa Creme, Parker Laboratories, Fairfield, New Jersey) and immersed in water. The electrodes length was sufficient to wrap the width of the muscle belly. The electrodes were placed in approximately the same position for each subject. Tetanic stimulation was evoked with electrodes connected to a high-voltage stimulator (Digitimer Stimulator Model DS7H + Hertfordshire, UK). A stimulation frequency of 50 Hz was maintained for a duration of 3 s with a pulse duration set at 50 μs. Stimulation was started with voltage at 100 V and amperage at 200 mA and progressively increased by 200 mA until 1 ampere was reached. If the subject could tolerate greater force then voltage was increased incrementally by 50 V. The purpose of the tetanic stimulation was to determine the maximum evoked force output that could be tolerated (pain perception) by the individuals.

**Maximum Voluntary Contraction (MVC) Force**

All subjects performed 2–3 MVCs trials. Verbal instructions were given to each subject to maximally contract the elbow flexors as hard and fast as possible. During the contraction, verbal motivation and visual feedback was provided by the investigator to promote a maximal response. The isometric contraction lasted for 4-5 s. Subjects were given a rest period of at least 2 min between each MVC. Peak force was measured as the greatest difference between the pre-MVC or resting value (approximately 1s prior to contraction) and the greatest force amplitude. If there was a >5% difference between the first 2 MVC trials, the subject was asked to perform a third trial, and the highest MVC force was recorded.

**Visual Analogue Scale**

A soreness rating scale was used with a visual analogue scale (VAS) to collect the soreness perception levels prior to testing. Since the subject’s were maximally exerting and physically restricted during the MVCs and with the treatment applications, subjects were instructed to verbally report the perception of soreness levels to the researchers who would record the response on the 10-point, 100 mm VAS scale. VAS has been reported to be a valid indicator of pain with excellent consistency.

**Statistical Analysis**

Treatment analysis included a 2 way repeated measures ANOVA (2 × 4)(GB-STAT for MS Windows, version 7.0, Dynamic Microsystems Inc., Silver Spring, MD) with factors including treatment intervention (menthol based topical analgesic and ice) and time (T1-T4). The effect of DOMS on voluntary and evoked forces was analyzed with repeated measures ANOVA. Differences were considered significant when p values were below an alpha level of 0.05. A post hoc Bonferroni- Dunn’s procedure was used to detect specific significant differences. Effect sizes (ES = mean change / standard deviation of the sample scores) and confidence intervals were also calculated and reported. Cohen applied qualitative descriptors for the effect sizes with ratios of <0.41, 0.41-0.7, and >0.7 indicating small, moderate and large changes respectively. Data were reported as mean ± SD.

**RESULTS**

A post-hoc analysis of the statistical power (for a two-sided test) calculated for an alpha of 0.05 ranged from 0.2 for MVC force measures (insignificant findings) to 0.84, 0.97 and 0.98 for tetanic force, VAS scores at rest and VAS scores during the MVC respectively. There were no significant differences between groups for any baseline (T1) measures.

**Voluntary Muscle Force and Activation**

There was no significant main effect or interactions for the treatment interventions. There was a significant
(p = 0.04; ES=0.54) main effect for time, with a DOMS-induced decrease in MVC force of 17.1% from T1 to T2 (Figure 1). There were no significant MVC force differences between T2, T3 and T4 (Table 1).

**Evoked Muscle Force**

There was a tendency with a large effect size (p = 0.06; ES=1.2) for tetanic force to decrease over time with 43.4%, 35.1%, and 31.2% decreases of T2, T3 and T4 respectively, compared to T1 (Figure 2). Tetanic force changes illustrated a significant main effect for the treatments (p<0.05; ES=1.1) with the menthol based topical analgesic allowing 116.9% greater tetanic force (89.4 N ± 60.7) output than the ice treatment (41.2 ± 43.6). Although not statistically significantly different (p=0.17), tetanic forces following the ice treatment at T2, T3 and T4 were 56.5%, 78.7% and 66.1% lower than tetanic forces following the respective times with the Biofreeze treatment (Table 1).

**Pain Scales**

There was no significant difference in pain perception pre-treatment. Although there was no significant

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**Figure 1:** Figure illustrates a main effect for time associated with changes in maximum voluntary contraction (MVC) force of the non-dominant elbow flexors. The asterisk indicates a significant (p=0.04) difference between T1 (pre-test) and T2 (2 days following DOMS and 20 min following intervention application) MVC force. Columns and bars represent means ± standard deviation (SD).

**Figure 2:** Figure illustrates a tendency (p = 0.06) with a large effect size (ES = 1.2) for a main effect for time (data collapsed over treatments) associated with evoked tetanic force of the non-dominant (DOMS-induced) elbow flexors. Columns and bars represent means ± standard deviation (SD).

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**Table 1.** Treatment by time interactions. The first series of numbers represents mean ± standard deviations whereas the subsequent numbers below represent the 95% confidence interval (CI).

<table>
<thead>
<tr>
<th></th>
<th>MVC Force</th>
<th>Tetanic Force</th>
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<tr>
<td></td>
<td>T1</td>
<td>T2</td>
</tr>
<tr>
<td>Menthol</td>
<td>393.05 ± 127.6</td>
<td>359.3 ± 101.9</td>
</tr>
<tr>
<td></td>
<td>CI: 307.6-478.5</td>
<td>CI: 291.1-427.5</td>
</tr>
<tr>
<td>Ice</td>
<td>367.9 ± 180.4</td>
<td>271.96 ± 137.1</td>
</tr>
<tr>
<td></td>
<td>CI: 247.2-488.6</td>
<td>CI: 180.1-363.7</td>
</tr>
<tr>
<td>Menthol</td>
<td>96.6 ± 88.5</td>
<td>70.4 ± 37.1</td>
</tr>
<tr>
<td></td>
<td>CI: 37.1-158.1</td>
<td>CI: 45.6-95.3</td>
</tr>
<tr>
<td>Ice</td>
<td>82.2 ± 67.7</td>
<td>30.6 ± 25.5</td>
</tr>
<tr>
<td></td>
<td>CI: 36.9-127.5</td>
<td>CI: 13.5-47.6</td>
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</table>

ES= Effect size; A single asterisk (*) represents a main effect for time with MVC force decreasing significantly (p=0.04) from T2 to T1. A swirl (~) represents a tendency (p=0.06) for time with tetanic force at T1 to be significantly greater than T2, T3 and T4 (combined over treatments).
group by time interaction, soreness perception associated with the MVC showed trends with large effect size for both treatment and time. The soreness associated with a MVC following ice application (3.9 ± 0.5) tended to be 33% greater (p=0.08; ES=1.8) than following the topical analgesic application (3.0 ± 0.4). Soreness associated with a MVC had a tendency with a small effect size (p=0.1; ES=0.12) to decline over time with 13.1% and 17.7% less soreness respectively, perceived at T3 (3.3 ± 0.98) and T4 (3.1 ± 1.2) compared to T1 (3.8 ± 1.02). There was a significant (p=0.025; ES=1.2) difference in soreness perception with the VAS scale between the application of ice and the menthol based topical analgesic. Soreness perception was 63.1% less with application of the topical analgesic (1.1 ± 0.4) compared to the ice (3.1 ± 1.7).

DISCUSSION
The most important results of this study suggest that a menthol based topical analgesic was more effective than ice for relieving soreness associated with DOMS while at rest or during muscle contractions. The topical analgesic also permitted greater evoked tetanic forces to be produced as compared to ice.

Menthol and ice are widely used as topical analgesics. Ice is reported to be effective in reducing pain with soft tissue injuries and has also been widely used in relieving the symptoms of DOMS. It is suggested that the cold temperature significantly reduces the pain perceived due to DOMS. However, other studies report that ice massage have minimal effects on reducing DOMS symptoms. Although ice is commonly used to alleviate pain, there is conflicting evidence regarding its effectiveness for relieving DOMS. In the present study ice was less effective than a menthol based topical analgesic for relieving DOMS symptoms. The menthol based topical analgesic showed both large magnitudes of change over the testing periods as well as achieving minimal clinical importance. A number of studies have indicated that a change of 10-13 mm on a VAS scale of 100 mm represents the minimal clinically significant difference. The present study anchored numbers from 0-10 with a distance of 10 mm between each numeral. The VAS score with the menthol based topical analgesic of 1.1 was substantially lower than the score associated with the ice treatment (3.1) illustrating a clinically significant difference in pain perception.

Menthol has been reported to be effective in relieving pain with mild to moderate muscle strains. Topical application of a menthol gel along with the chiropractic adjustment showed significant reduction in low back pain. Yosipovitch et al. reported that while menthol has a high skin irritating effect it did not differ from alcohol in reducing itch and pain sensations. However, Galeotti et al. indicated that menthol’s analgesic properties are mediated through a selective activation of opioid receptors. The feeling of coolness experienced when applying menthol is achieved by sensitization of the thermosensitive neurons that also possess analgesic properties. Using mice, Galeotti et al. reported an increase in heat pain threshold. Furthermore, menthol has been shown to activate temperature-activated transient receptor potential (TRP) ion channels such as TRPM8, TRPV3 and inhibits TRPA1 providing a rationale for its use as an analgesic. Stimulation of these thermosensitive neurons is also associated with an analgesic effect. Afferent thermosensitive neurons are stimulated by the application of menthol, have an inhibitory effect on the nociceptive afferent neurons and dorsal-horn neurons, which conduct pain impulses to the thalamus.

Another possible mechanism for the analgesic effect of menthol may be related to the inflammation or swelling associated with DOMS. Olive et al. reported a significant reduction in vascular conductance within 60s of menthol application, which was maintained for at least 10 minutes. Similarly animal studies have shown a reduced pressor response to exercise (decreased blood pressure) reducing blood flow to the application area. Unfortunately the extent of swelling was not measured in the present study and thus the effect of the menthol gel on DOMS-induced inflammation cannot be verified or quantified in this study. Hence, the mechanisms underlying the lower soreness scores on the VAS cannot be specified in the present study but may be attributed to one or a combination of inflammation reduction, counterirritant activation and inhibition of specific thermosensitive ion channels, or opioid receptors.

The menthol based topical analgesic permitted greater evoked tetanic forces following DOMS than ice. Unfortunately, VAS for pain was not employed during the tetanic contractions. However, all participants in this
study and the many previous studies from this labora-
tory have all commented on the substantially greater
discomfort experienced during evoked tetanic versus
voluntary contractions. Electrical stimulation of mus-
cle through the skin can activate cutaneous pain
receptors, with greater magnitudes of pain experi-
enced with increasing frequency of stimulation. Fur-
thermore the stimulator provides synchronous
muscle activation rather than a typical physiological
asynchronous stimulation resulting in a cramp-like
sensation. This cramp-like contraction can also stim-
ulate mechanical nociceptors contributing to the pain
sensation. Hence in the present study, the milder
discomfort associated with a voluntary contraction
did not allow subjects to differentiate between the
topical analgesic and ice but the greater discomfort or
pain of the tetanic cramp-like contraction was amelio-
rated to a greater degree by the menthol based topical
analgesic. Thus the menthol based topical analgesic
provided greater pain tolerance allowing higher evoked
contraction forces to be produced. In terms of injury
rehabilitation, the menthol-based analgesic would allow
higher contraction forces to be elicited with functional
electrical stimulation training.

The greatest limitation of the present study is related
to the individual responses to pain. Behm and St-
Pierre reported a correlation 0.1 between pain and
muscle activation. The high variability with some of
the data in the present study also reflects the very dif-
ferent responses of each individual to pain. Thus, pre-
dictably there was no significant correlation between
pain and changes in force. A further limitation could
have been that the treatments could have distinctive
time courses. The present study utilized early and
delayed testing times for the treatments in order to
identify if one treatment was more likely to have a
greater effect soon after or later after application.

CONCLUSIONS

The results of the present study indicate that a menthol
based topical analgesic was more effective than ice for
decreasing DOMS-induced symptoms of pain and
increasing evoked tetanic force. Hence, a menthol
based analgesic would be recommended for reducing
DOMS-induced symptoms for at least 35 minutes after
the application. While patients with injuries were not
employed in this study, the greater tetanic force with
the menthol analgesic might suggest that more intense
or aggressive muscle stimulation therapy during reha-
bilitation might be possible with such a therapeutic
agent. Finally DOMS was used as a model to induce
pain in the present study. The results may also apply to
other musculoskeletal pain afflictions; however further
research should investigate injured populations (e.g.
strains, sprains). Furthermore, previous research indi-
cates that the effects of menthol-based gels may work
within a minute of application making them more time
efficient than ice.

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ABSTRACT

**Background and Purpose:** Athletes reporting chest pain are challenging to diagnose and equally challenging to treat. The majority of chest pain is musculoskeletal in origin, yet differentiating these from other more serious conditions should be the initial primary focus. The ability to reproduce the patient’s symptoms aids in the differential diagnostic process. The purpose of this case report is to illustrate the use of dry needling (DN) to aid in the diagnosis and treatment of focal chest wall pain.

**Case Descriptions:** A 22 year-old male military athlete with anterior chest pain, refractory to traditional physical therapy, was evaluated and treated with dry needling.

**Outcomes:** Favorable results were achieved as demonstrated by clinically meaningful improvements in the Patient Specific Functional Scale, the Global Rating of Change score, and his physical performance which allowed this athlete to return to competition and military training.

**Conclusion:** Dry needling in the hands of properly trained providers may aid in diagnosis and treatment of focal chest wall syndromes.

**Key Words:** chest pain, costochondritis, dry needling, military athlete, physical therapy

**Level of Evidence:** Therapy, Level 4
INTRODUCTION

Athletes who seek care for a primary complaint of focal chest pain in the direct-access sports physical therapy setting present unique challenges. When faced with any new patient consultation, especially a patient reporting “chest pain”, the physical therapist must determine whether the patient is appropriate for physical therapy or if he or she requires immediate medical referral. Visceral or somatic origins of chest pain include the heart, lungs, pleura, liver, and stomach. While the cause of chest pain is often musculoskeletal in origin and 80% of all chest pain seen in primary care is benign, differentiating between cardiac-related, visceral, and musculoskeletal chest pain conditions is essential for formulating an accurate diagnosis and developing an appropriate course of action.

Once the patient is determined to have pain of musculoskeletal origin, physical therapy is an appropriate setting for definitive care. The challenge for the physical therapist then becomes conducting a focused physical examination and designing an effective treatment plan. When an athlete reports a history of direct trauma, such as a contact injury to the chest from an opponent’s elbow, the evaluation and treatment can be straightforward. In patients who present with an insidious onset of chest wall pain and an unremarkable history, the list of differential diagnoses can be extensive (Table 1). While a myriad of contributing factors must be considered when evaluating focal chest pain, the highest percentages of musculoskeletal-related chest pain have been reported to originate from either costochondritis, segmental dysfunction of the cervicothoracic spine, or local muscular tenderness.

One suggested contributor to focal chest wall pain that may cause both local muscular tenderness and referred symptoms is local neuromuscular dysfunction and the presence of so-called muscle trigger points (MTrPs). MTrPs are described as localized hyperirritable areas in skeletal muscle associated with hypersensitive palpable taut bands, which have been reported in the literature as either “active” or “latent”. Active MTrPs are suggested to spontaneously contribute to local or referred symptoms without manual stimulation and may alter muscle activation and joint range of motion (ROM). Latent MTrPs may also alter muscle activation patterns and affect range-of-motion without contributing to pain referral unless manually stimulated. Variability between patients and muscle structure or type may contribute to poor reliability in detecting focal contractile changes such as those suggested to be MTrPs. Despite concerns regarding reliability and accuracy of localizing and identifying MTrPs, their treatment is frequently included in the plan of care for numerous musculoskeletal conditions, including pain in the chest wall. Various techniques and modalities have been described in the literature that may be used to treat MTrPs, including stretching, soft tissue mobilization, dry needling (DN), and injection therapy.

Table 1. Potential causes of chest pain in athletes.

<table>
<thead>
<tr>
<th>Musculoskeletal</th>
<th>Cardiac</th>
<th>Respiratory</th>
<th>Gastrointestinal</th>
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<tbody>
<tr>
<td>Sternocostal joint sprain</td>
<td>Myocardial infarction</td>
<td>Asthma</td>
<td>Gastroesophageal reflux disease</td>
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<tr>
<td>Intercostal muscle strain</td>
<td>Pericarditis</td>
<td>Exercise induced asthma</td>
<td>Esophagitis</td>
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<tr>
<td>Rib contusion</td>
<td>Myocarditis</td>
<td>Lower respiratory infection</td>
<td>Hiatus hernia</td>
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<tr>
<td>Referred pain from the thoracic spine</td>
<td>Aortic dissection</td>
<td>Pneumothorax</td>
<td>Peptic ulcer</td>
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<tr>
<td>Stress fracture (rib, manubrium, or sternum)</td>
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<td>Pleuritis</td>
<td>Cholecystitis</td>
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<tr>
<td>Chondral cartilage injury (fracture)</td>
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<td>Pulmonary embolus</td>
<td>Pancreatitis</td>
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<tr>
<td>Rib tip syndrome</td>
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<td>Oesophageal motility disorders</td>
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<tr>
<td>Costochondritis</td>
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<tr>
<td>Tietze’s syndrome</td>
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<tr>
<td>Osteoarthritis (sternoclavicular, manubriosternal, or costovertebral)</td>
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</table>
illustrate the use of DN to aid in the diagnosis and treatment of focal chest wall pain.

CASE DESCRIPTION:
INITIAL EVALUATION AND TREATMENT (PROVIDER #1):
The subject was a 22 year-old right upper extremity dominant male who presented to a direct-access sports physical therapy clinic with a primary complaint of left-sided anterior chest pain for one month duration. While symptoms had been gradually worsening over the past month, the patient reported he experienced a “severe” bout of pain shortly following pushups two days prior. The patient attributed his pain to increased physical training in preparation for the Sandhurst Competition, an international military academy competition consisting of high-intensity endurance and obstacle negotiating challenges.24 Resting pain was reported at 3/10 which increased to 7/10 on a numeric pain rating scale (NPRS) with push-ups, bench press, or similar resistance activities. He denied history of any serious cardiopulmonary conditions or direct trauma to the upper extremity, chest, neck, or upper back. Physical examination revealed a well-appearing, muscularly developed and otherwise healthy male in no apparent distress. Observation revealed no bruising, swelling, or deformities. Cervical, thoracic, and bilateral upper extremity active range of motion were pain free and within normal limits. Gross manual muscle testing of the upper extremities was 5/5 and equal bilaterally, with minor anterior chest wall discomfort reported during resisted left shoulder flexion, abduction, and internal rotation. Bilateral pectoralis minor tightness was demonstrated when examined in supine,25 left greater than right. Pain was reproduced with palpation to the anteromedial aspect of the left ribs 2-4 as well as the left side of the sternum and corresponding costochondral joint (Figure 1, points 11-13).

Based on the initial history and evaluation, including reproduction of symptoms with palpation of the anterior rib and costochondral area, the therapist concluded that the patient's condition was musculoskeletal in nature and was primarily due to overuse. Consistent with the patient history and presentation of localized sharp pain at the costal cartilages, a working diagnosis of “costochondritis” was made, which is often the term used for conditions characterized by pain and local tenderness without focal swelling in the costochondral region.4,8,10 The treatment plan included home exercises consisting of pectoralis stretching and thoracic active range of motion exercises with an additional recommendation to avoid aggravating activities.11

FOLLOW-UP VISITS AND CARE (PROVIDER #1):
Following two weeks of the home exercise program and rest, the patient reported resting pain had resolved (0/10), and pain with resisted activity was unknown since he had avoided aggravating activities as instructed. Compared to the initial evaluation, there were no significant changes on physical examination although subjectively less pain was reported with palpation of the anterior chest wall. The patient was advised to continue the current exercises and to gradually increase activity as tolerated.

Two weeks later, the patient reported his symptoms had returned as he increased his activity (NPRS at rest 3/10, NPRS with activity 7/10). Upon more thorough cervicothoracic spine examination conducted during this visit, the therapist determined there to be painfree hypomobility throughout the upper thoracic spine from T1-T7.26,27 The hypomobile segments were immediately treated with supine thoracic regional manipulation and a cervicothoracic junction distraction manipulation.28 Grade I & II mobilizations of the costochondral joints were performed as described by Greenman,28 at the anterior aspect of ribs 2-5 with the therapist's thumb and thenar eminence at the superior aspect of the rib shaft.11 An additional two weeks later, the patient stated his symptoms were unchanged. The treating provider considered DN as a potential treatment option; however, he had not received training/certification to safely administer this intervention. He consulted with a colleague who did have the appropriate training who suggested a trial of needling may stimulate a healing response. The patient agreed to obtain a second opinion and to consider the DN treatment.

INITIAL EVALUATION AND TREATMENT (PROVIDER #2)
At the time of this evaluation, the patient reported that his chest pain was overall unchanged compared to 3
months prior – although symptoms had improved for a couple weeks with rest but returned with activity. Current reported pain was 4/10 (resting) and 7/10 (with resistive activity) on the NPRS. During this visit, the patient was asked to complete a Patient Specific Functional Scale (PSFS), rating the difficulty level of several “important” activities on which he indicated “push-ups” to be his most difficult activity (Figure 2). There are no specific outcomes measures reported in the literature for assessment of chest wall syndromes, however the PSFS has been reported to be a valid, reliable, and responsive outcome measure for patients with neck pain, back pain, and upper quarter complaints.\textsuperscript{29-31} He further stated that prior to onset of his current pain he was able to perform over fifty push-ups during his most recent physical fitness assessment (Army Physical Fitness Test, 2-minute push-up event).

The majority of physical examination findings (ROM, strength, etc.) coincided with those described previously. Examination of the cervicothoracic region, including soft tissue, transverse processes, and rib angles\textsuperscript{26} was unremarkable. During palpation, this provider determined the greatest discomfort corresponded to the area of the costochondral joint at the level of the second rib (Figure 1, point 11). Several focal symptomatic areas of local muscular tenderness, consistent with the description of MTrPs, were also located in the left pectoralis major and pectoralis minor muscles using flat and pincer-type palpation (Figure 1, points 8, 9).\textsuperscript{15,22}

Following this history and physical examination, DN was discussed with the patient as a potential treatment option, including a thorough discussion of precautions and risks associated with needling in the thoracic region. After written informed-consent was obtained, dry needling was performed over the second rib\textsuperscript{32} at the costochondral joint and along the soft tissues superficial and corresponding to the second rib. During the dry needling of the costochondral joint and soft tissue, the patient reported reproduction of his symptoms. A reproduction in symptoms served to add diagnostic value by confirming that the patient's symptoms were musculoskeletal in origin. The needle was pistoned repeatedly (manipulated up and down without withdrawing the needle) targeting the areas of symptom reproduction and the patient consistently reported reproduction of his symptoms, although no local twitch responses were recognized (Figure 3, top). While DN was potentially indicated to the pectoralis muscles at this time, the therapist elected to assess the patient's response to direct needle stimulation of the costochondral structures prior to adding a second treatment location. The patient did not report any significant changes in symptoms immediately following therapy. He was advised to perform shoulder active range of motion with gentle unilateral pectoralis muscle stretching\textsuperscript{33-35} as a home exercise program, and to avoid aggravating activities.

Based on the history and evaluation, including reproduction of symptoms with palpation and needling of the costochondral area, the second therapist concurred with the original clinician that the patient's condition was musculoskeletal in nature; however, the diagnosis was generalized to “chest wall syndrome”. It has been suggested that musculoskeletal...
pain localized to the chest wall is best termed “chest wall syndrome”, as the morphological and physiological basis is elusive and the exact nature is challenging to ascertain. 

**TREATMENT AND FOLLOW-UP VISITS (PROVIDER #2)**

Two days later the patient returned for re-evaluation and treatment. He reported his overall pain level was unchanged (4/10 at rest) although he stated that his symptoms seemed to be more focal. During this visit, in addition to DN the second rib costochondral region, DN was also directed to the palpable tender bands of soft tissue in his left pectoralis muscle region (Figure 3, bottom). Local twitch responses were elicited, and the patient again reported reproduction of his focal chest wall symptoms, with needling at both locations. Immediately following needling therapy the patient reported feeling “looser” in his chest muscles and the previously palpable bands of soft tissue were no longer symptomatic. No additional exercises were prescribed at that time.

Three days later, the patient subjectively reported feeling “50% better” overall, rated his pain as 2/10, and he was able to demonstrate five pain free push-ups at that time. During this visit the patient agreed to defer further needling treatment to assess the

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**Figure 2.** Patient Specific Functional Scale. The patient self-selected four activities that were difficult to perform due to his symptoms. For example, activity number 4 “Equipment Run (wearing full kit)” involves running in boots with full military gear.

**Figure 3.** Locations used for dry needling technique: costochondral region of 2nd rib (top), and pectoralis major muscle (bottom).
duration of symptom improvement from the previous treatment. He stated that he intended to resume training as tolerated for the Sandhurst Competition with his teammates and was encouraged to continue pectoralis muscle stretching.

An additional week later, the patient reported pain at rest was 0/10 and pain with activity was 2/10 (localized to the pectoral muscles). The patient further stated he performed a cumulative total of 100 repetitions of push-ups throughout the previous weekend (two days prior) with minimal discomfort. Additionally, his PSFS was improved from baseline (Figure 2). He was treated with DN to the left pectoralis major muscle, in the area of reported symptoms during activity, with local twitch responses elicited during therapy. Additionally, he was provided a closed-chain upper extremity exercise program to help prepare him more completely for his upcoming endurance and obstacle course event consisting of a push-up progression program, upper extremity box drills, and plyometrics.

OUTCOME
At one month following the initial dry needling treatment the patient reported that he had been pain free at rest and with activity for greater than a week, and he successfully completed the Sandhurst Challenge without significant symptoms. His composite PSFS score, which was initially reported at 4.7, had improved to 9.5 (Figure 2). The minimum important difference (MID) in the overall PSFS for patients with upper extremity conditions is 1.2 points. Each individual PSFS score improved between 4 (bench press) to 6 (pushups) points (Figure 2). The minimum detectable change in single activities on the PSFS is 3 points. In addition, this patient's Global Rating of Change (GROC) was scored at +6. The GROC used in this case was a 15-point scale in which patients assess their impression of their global clinical change from the time they began treatment, ranging from “A very great deal worse” to “A very great deal better”. The GROC is considered a valuable tool to assess self-perceived change in patient's symptoms, with greater than 5 point change considered clinically meaningful.

At a follow-up visit 3 months later, the patient continued to report significant improvement in symptoms with intermittent minor discomfort during strenuous exercise activities. He reported overall that he has continued to feel over 90% improved and rated his GROC at +6. He reported he was able to complete several advanced military physical training courses that required strenuous repetitive use of the upper extremities. He stated that he was able to perform 50 repetitions of push-ups before onset of discomfort, was able to perform the same number of pushups as before initial onset of his problem and estimated having performed several hundred push-ups during the previous month.

DISCUSSION
This case report illustrates the use of dry needling targeting the costochondral region and pectoralis musculature to aid in the diagnosis and treatment of focal chest wall pain. Because traditional physical therapy management did not yield significant changes in the patient's symptoms, this patient was referred to a physical therapist with advanced training in DN. During the evaluation, DN to the costochondral joint and focal soft tissue tenderness consistent with the description of MTrPs in the pectoralis musculature reproduced this patient's familiar chest wall symptoms. This information served to confirm the current symptoms were most likely musculoskeletal in nature. Despite this being a challenging area to manage which is often recalcitrant to other therapies, after 4 treatment sessions of DN directed to the costochondral joints and pectoralis musculature over a 1 month period of time, this patient achieved substantial improvements in pain and function. Although case studies such as this illustrate a potential response to treatment and favorable outcomes, they do not provide sufficient information to determine a cause and effect relationship.

Musculoskeletal chest wall pain has traditionally been a difficult area to evaluate and treat. Injection therapy with local anesthetics or corticosteroids has been previously described as a treatment method for costochondral-related chest wall pain. Since results of previous research studies have indicated DN may be as effective as injection therapy for various conditions, a trial of DN was deemed appropriate for this case and was performed to potentially stimulate a healing response. Following the first two treatments of DN, the subject was able to resume
training and following two additional treatment sessions he was able to successfully participate in the physically demanding Sandhurst Challenge.

Needling has been reported in the literature as an effective adjunct to treatment for numerous musculoskeletal conditions. Furthermore, in some cases, needling may aid in the diagnostic process by reproducing the patient’s symptoms. DN is a potentially valuable technique when used to differentiate between symptoms originating in muscle tissue from other structures. The ability to reproduce the patient’s symptoms, such as described in the current case, has great value aiding in the differential diagnostic process. If DN elicits a local twitch response in conjunction with the patients familiar pain the cause is likely to be, at least partly, of muscular origin.

Several conceptual models explaining the mechanism of action of DN have been described in the literature, including the radiculopathy model, the MTrP model, and the spinal segmental sensitization model. Clinicians practicing based on the trigger point model target specific locations in muscle tissue thought to be MTrPs, although the reliability and accuracy of detecting these focal muscle lesions lacks strong support in the literature. Patient expectations and the placebo effect can provide significant results, and there is limited evidence to determine if needling has an effect beyond placebo. In this case the patient failed to improve with traditional therapies and therefore the authors elected to use a functional treatment approach, focusing on patient-specific responses in function following DN intervention. Favorable changes were demonstrated after localizing therapy with DN to the costochondral joint and local areas of tenderness associated with the patient’s primary complaint.

The ability to elicit a local twitch response (LTR) is proposed to confirm that the needle has affected an MTrP. Hong and colleagues stated that outcomes are significantly better when a LTR is elicited during needling. The authors’ experience has been that patients frequently feel little or no discomfort during insertion of the needle, and depending on the target tissue, typically only respond with discomfort following several millimeters to centimeters of depth of needle advancement has been achieved. The depth of needle insertion prior to patient feedback leads us to believe we are truly affecting the target tissue and not simply the superficial or subcutaneous sensory tissue, since the depth of needle insertion has exceeded that of the superficial soft tissue. Although not reported elsewhere, non-contractile tissue such as are described in the current case, may also benefit from needling therapies. Further research is required to determine responsiveness to needling various musculoskeletal structures such as ligaments, tendons, and entheses.

It should be emphasized that only properly trained providers with an extensive knowledge of human anatomy should perform DN. Physical therapists have been recognized as neuromusculoskeletal clinical experts with extensive training in anatomy, physiology, palpation, and manual therapies. Several DN training programs are available in the United States for clinicians whose state practice act allows needling, typically the thoracic region is not covered in introductory and beginning level courses.

Because DN is an invasive procedure, great caution needs to be heeded when DN is performed in the vicinity of vital internal organs. Risks associated with needling the thoracic region include pneumothorax, cardiac trauma, and infection. Needling is safe, however, when performed by properly trained health professionals who use the proper safety precautions. The risk of iatrogenic pneumothorax from dry needling in the thoracic region is likely similar to that of other needling therapies such as acupuncture, which has an estimated incidence of less than 1/10,000. Handwashing and thorough cleaning of the area to be treated are basic steps employed to reduce the risk of infection. Universal precautions, such as wearing gloves, should be standard practice for all clinicians performing invasive procedures in which they may come into contact with bodily fluids. To the authors’ knowledge, no adverse events have been reported when following the appropriate procedures and precautions and there are no cases of pneumothorax, cardiac trauma, or infection from dry needling by physical therapists reported in the literature.

While DN is an accepted treatment technique by therapists in many countries, relatively few physical therapists in the United States have received training and certification in DN. In 2009, the Executive
Committee of the American Academy of Orthopaedic Manual Physical Therapists issued a position statement that dry needling falls within the scope of physical therapy practice. Recently, the American Physical Therapy Association published an educational resource paper regarding physical therapists use of DN. As with any modality or rehabilitation technique, research is needed to determine the most effective parameters in which DN should be implemented.

CONCLUSION
Although the majority of focal chest wall pain is attributed to musculoskeletal dysfunction, effective treatment strategies remain elusive. The substantial change in function and symptoms illustrated in this case study suggests that dry needling in the hands of a qualified provider with advanced training may aid in treatment for patients with focal chest wall pain of musculoskeletal origin. While this treatment modality has great potential for aiding as an adjunct to management in musculoskeletal conditions, future research is needed to evaluate the effectiveness of dry needling to determine what conditions would most likely benefit from needling techniques. Additionally, research is needed to determine best practices regarding duration and frequency of this treatment modality.

REFERENCES


ABSTRACT

Background and Purpose: Hamstring injury is a common occurrence in sport and there has been limited success in reducing this rate of recurrence to date.

Description of Topic with Related Evidence: High speed running requires eccentric strength when the hamstring muscles are in a lengthened state. The lengthened state occurs when the hip is in flexion and the lower leg moves into extension, thus lengthening the two joint hamstring muscle over both articulations upon which they act. There is evidence to suggest that athletes who have sustained a hamstring strain lack strength when the muscle is utilized during performance in a lengthened state.

Purpose: To examine the risk factors contributing to such a high recurrence rate and propose a unique rehabilitation strategy addressing these factors in order to decrease the rate of reinjury.

Discussion/Relation to Clinical Practice: Failing to increase an athlete's eccentric strength in a lengthened position after a hamstring injury may predispose an athlete to subsequent reinjury. Incorporating lengthened state eccentric training may help reduce the rate of reinjury.

Key words: Hamstring strain, lengthened state eccentrics

Level of Evidence: Level 5
BACKGROUND AND PURPOSE
Hamstring strains are one of the most frequently occurring injuries in sport. They can be challenging and frustrating to treat because of the high recurrence rate. Hamstring strains account for 12-16% of all injuries in athletes,1-5 with a reinjury rate reported as high as 22-34%.5-7 Furthermore, recurrent hamstring strains have been shown to result in significantly more time lost than first time hamstring strains.1 In order to decrease this rate we must first examine the potential risk factors for injury and then address them accordingly. While there is a myriad of studies focusing on risk factors for hamstring strains, there is a paucity of high-level evidence with regards to the identification of these risk factors as well as rehabilitation with an emphasis on reducing the risk of reinjury.8 The purpose of this clinical commentary is to examine the risk factors contributing to such a high recurrence rate and propose a unique rehabilitation strategy addressing these factors in order to decrease the rate of reinjury.

RISK FACTORS FOR HAMSTRING STRAINS
Several risk factors for hamstring strains have been proposed in the literature, including: decreased flexibility,9-10 strength deficits,11 muscle fatigue,12 poor core stability,13 lack of proper warm-up,14 poor lumbar posture,15 and a prior hamstring injury.16,17 Previous hamstring injury appears to be the most consistent risk factor for restraining the hamstring. Engenbetesen et al17 examined over 500 amateur soccer players prospectively and among all the risk factors examined, previous acute hamstring strain was the strongest risk factor for recurrent strain. In fact, a previous hamstring strain has been shown to increase the risk of a recurrence two to six times.16-18

MECHANISM OF INJURY
Hamstring strains can occur during a variety of athletic maneuvers and situations, resulting in several distinct types of injuries, each with a unique mechanism. The first occurs during a stretching of the muscle at extreme joint positions, such as in a Rockette style high kick.19,20 These injuries generally occur to the proximal free tendon of the semimembranosus tendon and appear to be less severe initially but ultimately require a longer recovery time than hamstrings strained by other mechanisms.21 The second mechanism of hamstring strain occurs during high speed running.1,22 There remains some debate in the literature as to which phase of the sprinting cycle in which hamstring strains occur: the early stance phase or the late swing phase. Proponents of hamstring injury during early stance phase of sprinting suggest it is during this phase in which the muscle absorbs the most force as a result of high ground reaction forces.23 In vivo studies of the Achilles tendon in sprinting24 and patella tendon in jumping25 and hopping26 show that the forces are much higher in the concentric stance phase as opposed to the eccentric swing phase and this may apply to the hamstrings as well. There is also evidence to suggest hamstrings may be susceptible to injury in the late swing phase. Previous studies demonstrate that the hamstrings are under a large amount of stress in the terminal swing phase as the hamstrings eccentrically contract to absorb the kinetic energy and slow the lower limb.27 In a biomechanical study Schache et al28 found that peak musculotendinous strain occurred during terminal swing phase of the sprinting cycle, suggesting that this period may pose the greatest risk for injury. They went on to recommend a rehabilitation program focusing on eccentric loading at longer muscle lengths.

To assess whether a reduction in force production at longer muscle lengths exists in athletes who have sustained a hamstring strain, Brockett et al29 examined the angle torque curves of previously injured subjects and compared them with the subjects’ uninjured leg as well as those of uninjured control subjects. The authors showed that the peak hamstring torque occurred at a significantly shorter muscle length in the previously injured hamstring when compared to controls, indicating what may be termed a shift in the length-tension curve. It is possible that when an athlete sustains a hamstring strain they potentially return to play with weakness at longer muscle lengths possibly predisposing them for a second hamstring strain during the eccentric terminal sprinting movement.

It has been well established in the literature that eccentric training is effective in the prevention of hamstring strains.1,30-33 The authors feel that the eccentric training should be done not just in the seated position from 90 degrees to full knee extension, but should include training in the lengthened state. We hypothesize that training in the lengthened state may help...
shift the curve to acquire the necessary eccentric strength at the end of the range of motion to avoid susceptibility to further injury. The absence of rehabilitation focusing on lengthened state eccentric training may explain the disproportionately high rate of recurrence. Therefore, it is the belief of the authors that complete rehabilitation of a strained hamstring should include lengthened state eccentric training in order to minimize exposure to further muscle strain. Unfortunately, despite the best prevention programs hamstring strain injuries still occur.

**POST INJURY REHABILITATION**

Table 1 outlines rehabilitation guidelines for a hamstring strain, with emphasis on lengthened state eccentric training in the latter stages. It is important to consider that these are general guidelines and a rehabilitation program should be custom tailored to address the specific deficits discovered in each athlete during the examination process.

In the acute stage of hamstring rehabilitation the treatment should focus on protecting the injury and minimizing range of motion and strength loss. Modalities such as ice, pulsed ultrasound, and laser are commonly utilized at this time. The athlete may begin pain free submaximal isometric strengthening at multiple angles (Figure 1) beginning at 48 hrs to allow the scar between fractured muscle fibers to achieve sufficient strength to avoid extensive separation of fiber stumps. These should be completed as a set of isometric knee flexion contraction at 30, 60, and 90 degrees of knee flexion by placing the injured limb on top of the into contralateral limb and contracting the strained hamstring. The hamstring should not be stretched into a painful range at this time but available hip and knee ROM should be maintained. Motion is also good for aligning fibers and increasing the strength of the lateral adhesion of fibers which protects the injured fibers from stump separation. The goals of this stage are to normalize gait and to obtain knee flexion strength at greater than 50% of uninjured length upon manual muscle testing at 90 degrees of knee flexion. Once these milestones are met the athlete may begin the next phase.

In the third and final phase the focus of the rehabilitation is on functional movements and eccentric strengthening in the lengthened state. Plyometric and sports specific training may be initiated as well as advanced balance exercise. Lengthened state eccentric training may be done using an isokinetic dynamometer. Using a setup previously described in the literature, the Biodex may be modified so patient is in hip flexion and then passively extends and flexes the knee into the end range of motion (Figure 4). The patient resists the passive motion as the knee is extended. It is imperative the hip is positioned in flexion as the knee extends to ensure the hamstring is truly at a lengthened state. Alternative lengthened state eccentric training may also be achieved without a dynamometer by keeping the involved thigh on the subject's chest while resisting an outside force via elastic resistance Thera-Band, cable column, (Figure 5) or manual resistance. This exercise may be performed by having the patient lay
supine pulling knee snugly into chest while hooked up to cable column or elastic resistance (Figure 5a). The patient then uses his or her arms to pull the knee into flexion and then slowly eccentrically resists the cable or elastic band as it pulls the knee into extension (Figure 5b). At the completion of this stage the athlete should have full strength throughout the range of motion and should be able to confidently perform all sport related tasks without limitation.

**RETURN TO PLAY CRITERIA**

Often athletes demonstrate full strength and ROM as assessed manually and with dynamometry in the clinic after completion of their rehabilitation, yet

<table>
<thead>
<tr>
<th>Table 1. Normalization of Strength/length Curve Protocol.</th>
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<tr>
<td><strong>Phase 1</strong></td>
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<tr>
<td><strong>Goals</strong></td>
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<tr>
<td>1. Protect healing tissue</td>
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<tr>
<td>2. Minimize atrophy and strength loss</td>
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<tr>
<td>3. Prevent motion loss</td>
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<tr>
<td><strong>Protection</strong></td>
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<tr>
<td>Avoid excessive active or passive lengthening of the hamstrings</td>
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<td>Avoid antalgic gait pattern</td>
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<tr>
<td><strong>Ice</strong></td>
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<td>2-3 times daily</td>
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<tr>
<td><strong>Therapeutic exercise (performed daily)</strong></td>
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<tr>
<td>1. Stationary bike</td>
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<tr>
<td>2. Sub maximal Isometric at 3 angles (90°, 60°, 30°) (Figure 1)</td>
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<td>3. Single leg balance</td>
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<td>4. Balance Board</td>
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<td>5. Soft tissue mobilization (STM)/Instrument assisted (IASTM)</td>
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<td>6. Pulsed Ultrasound (duty cycle 50%, 1 MHz, 1.2 W/cm²)</td>
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<td>7. Progressive hip strengthening</td>
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<td>8. Painfree isotonic knee flexion</td>
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<td>9. Active sciatic nerve flossing</td>
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<td>10. Ice with sensory electrical stimulation (e.g. Conventional TENS)</td>
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<tr>
<td><strong>Criteria for progression to next phase</strong></td>
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<tr>
<td>1. Normal walking stride without pain</td>
</tr>
<tr>
<td>2. Pain-free isometric contraction against submaximal (50%-75%) resistance during prone knee flexion (90°) manual strength test</td>
</tr>
<tr>
<td><strong>Phase 2</strong></td>
</tr>
<tr>
<td><strong>Goals</strong></td>
</tr>
<tr>
<td>1. Regain pain-free hamstring strength, progressing through full range</td>
</tr>
<tr>
<td>2. Develop neuromuscular control of trunk and pelvis with progressive increase in movement speed preparing for functional movements</td>
</tr>
<tr>
<td><strong>Protection</strong></td>
</tr>
<tr>
<td>Avoid end-range lengthening of hamstrings if painful</td>
</tr>
<tr>
<td><strong>Ice</strong></td>
</tr>
<tr>
<td>Post-exercise, 10-15 min</td>
</tr>
</tbody>
</table>
Table 1. Normalization of Strength/length Curve Protocol (continued)

<table>
<thead>
<tr>
<th>Therapeutic exercise (performed 5-7 d/wk)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Stationary bike</td>
</tr>
<tr>
<td>2. Treadmill at moderate to high intensity (progressive increasing intervals), pain-free speed and stride</td>
</tr>
<tr>
<td>3. Isokinetic eccentrics in non-lengthened state</td>
</tr>
<tr>
<td>4. Single-limb balance windmill touches without weight</td>
</tr>
<tr>
<td>5. Single leg stance with perturbation (eg ball toss, reaches)</td>
</tr>
<tr>
<td>6. Supine hamstring curls on swiss ball</td>
</tr>
<tr>
<td>7. STM/IASTM</td>
</tr>
<tr>
<td>8. Nordic hamstring exercise (Figure 3)</td>
</tr>
<tr>
<td>9. Shuttle jumps</td>
</tr>
<tr>
<td>10. Prone leg drops</td>
</tr>
<tr>
<td>11. Lateral and retro bandwalks</td>
</tr>
<tr>
<td>12. Sciatic nerve tensioning</td>
</tr>
</tbody>
</table>

Criteria for progression to next phase
1. Full strength (5/5) without pain during prone knee flexion (90°) manual strength test
2. Pain-free forward and backward jog, moderate intensity
3. Strength deficit less than 20% compared against uninjured limb
4. Pain free max eccentric in a non-lengthened state

Phase 3

Goals
1. Symptom-free (eg, pain and tightness) during all activities
2. Normal concentric and eccentric hamstring strength through full range of motion and speeds
3. Improve neuromuscular control of trunk and pelvis
4. Integrate postural control into sport-specific movements

Protection
Train within symptom-free intensity

Ice
Postexercise, 10-15 min, as needed

Therapeutic exercise (performed 4-5 d/wk)
1. Treadmill moderate to high intensity as tolerated
2. Hamstring dynamic stretching
3. Isokinetic eccentric training at end ROM (in hyperflexion, see figures 4, 5a, 5b)
4. STM/IASTM
5. Plyometric jump training
6. 5-10 yard accelerations/decelerations
7. Single-limb balance windmill touches with weight on unstable surface (Figure 2)
8. Sport-specific drills that incorporate postural control and progressive speed

Criteria for return to sport
1. Full strength without pain in the lengthened state testing position (Figure 7)
2. Bilateral symmetry in knee flexion angle of peak torque
3. Full range of motion without pain
4. Replication of sport specific movements at competition speed without symptoms
the recurrence rate remains disproportionately high. There is little evidence suggesting a valid functional test to determine return to play status after hamstring strain, which may mean rehabilitation professionals are returning athletes to competition before they have regained full strength in the lengthened hamstring position. In this regard Askling et al recently described a dynamic straight leg raise flexibility test, termed the H-test (Figure 6), to identify residual functional impairments that would preclude return to play. To perform the H-test, hamstring flexibility was calculated using data collected using an electrogoniometer during active ballistic hip flexion and conventional passive slow hip-flexion while in a supine position. A VAS-scale (0-100) was used to estimate experience of insecurity during active tests. Patients with hamstring injuries who were thought to be ready to return to sports based on standard clinical assessment demonstrated deficits in dynamic flexibility with the H-test despite having normal passive flexibility. The subjects also reported subjective insecurity while performing the test. Range of motion was assessed with an electrogoniometer which may not be widely available. Therefore the authors of this paper have performed the test using a non-retractable measuring tape and using simple trigonometry to calculate the angle during dynamic testing (Figure 6). Future research is required to establish the validity and clinical utility of this test in larger populations of patients.

As an alternative or compliment to the H-test the authors have developed and are currently testing the validity of a manual muscle test to examine hamstring weakness in the lengthened state. Since the hamstring muscle group is a two joint muscle, crossing both the hip and knee joint, both hip flexion and knee extension must be incorporated when testing the hamstring at its true functional length. To conduct this manual muscle test the athlete lays supine and holds pulls one thigh into hip flexion holding it snugly against the chest. The contralateral limb
Figure 3. **Nordic hamstring exercise.**

Figure 4. **Lengthened state eccentric training on the Biodex™.**

Figure 5 a,b. **Lengthened state eccentric training on cable column.**
remains flat on the table. The clinician then passively extends the knee until met with soft tissue resistance (i.e. putting a stretch on the hamstring). The clinician backs off by allowing the knee to flex 10 degrees from maximal stretch (Figure 7). From this position the clinician conducts the break test of the hamstring, and grades it using the tradition 0-5 scale established by Kendall or objectively by using a handheld dynamometer.

CONCLUSION
Hamstring injuries have long been the bane of athletes’ participation in sport among those who engage in sprinting and explosive movements, primarily because of both the high occurrence and recurrence rates. These injuries appear to create subsequent weakness at the muscle’s lengthened state, predisposing the athlete to further injury. Lengthened state eccentric training may increase the end range strength resulting in fewer reinjuries and therefore should be incorporated in the rehabilitation process. Further research is needed to determine the effect of lengthened state eccentric training on incidence of hamstring strain reinjury.

REFERENCES
13. Sherry MA, Best TM. A comparison of 2 rehabilitation progras in the treatment of acute


CASE REPORT-DIAGNOSTIC CORNER

THE USE OF DIAGNOSTIC MUSCULOSKELETAL ULTRASOUND TO DOCUMENT SOFT TISSUE TREATMENT MOBILIZATION OF A QUADRICEPS FEMORIS MUSCLE TEAR: A CASE REPORT

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Blake Boggess, DO, FAAFP1
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INTRODUCTION

Musculoskeletal ultrasound (MSK US) is emerging as a beneficial diagnostic tool for sports medicine and rehabilitation practitioners in identifying structural changes within tissues and joints. MSK US can also be used as an outcome measurement tool to determine whether subjective reports accurately represent structural changes within the injured tissue or joint. During rehabilitation, MSK US can be used to monitor treatment effectiveness as well as provide visual feedback during treatment to aid muscle contraction and relaxation.1

Diagnostic MSK US must be distinguished from therapeutic ultrasound commonly used in physical therapy as a modality. Diagnostic MSK US is used to evaluate soft tissues (muscle, ligament, etc.), detect fluid collection, and can also be used to visualize other structures such as cartilage and bony surfaces.1 Ultrasound wave frequencies, however, cannot penetrate into bone. Imaging of intra-osseous disease is generally not believed to be possible. The “real time” capability of ultrasound allows for dynamic evaluation of joint and tendons, which can be a valuable assessment tool. Ultrasound can be effectively used for guidance and localization during joint aspirations, injections, and biopsies. Finally, diagnostic MSK US is relatively inexpensive and can be convenient to use as compared to magnetic resonance imaging (MRI). Advantages of ultrasound also include its non-invasiveness, portability, and lack of ionizing radiation.1

Instrumented soft-tissue mobilization is often recognized as a beneficial adjunct to both stretching and exercise when treating a variety of musculoskeletal conditions. Some practitioners choose to augment the applications of soft tissue mobilization through the use of specific applicators such as those promoted by the Graston Technique® and ASTYM®. These soft tissue techniques as shown later in this commentary (Figures 2-5) have been supported in the literature to demonstrate efficacy based upon subjective reports and functional outcomes for a variety of conditions ranging from trigger thumb2 and carpal tunnel syndrome3 to plantar heel pain.4 Limited research data exists related to utilizing musculoskeletal ultrasound to both diagnose and document treatment of muscle tears. The authors of this case report investigated the use ultrasound to evaluate and document the efficacy of soft tissue treatment including the augmented applications of the deep pressure techniques in treating a quadriceps femoris tear.

CASE REPORT

A 24-year-old male competitive cyclist presented to the sports medicine clinic with complaint of right anterior thigh pain. He reported injuring a muscle of this thigh while playing a recreational soccer game twelve months prior to initial evaluation. The injury occurred when he was sprinting to pursue a pass and felt a popping sensation and immediate pain upon decelerating. Edema and ecchymosis were visible along the anterior mid-thigh within 24 hours following the injury onset. The patient reported a palpable “indentation” which became more apparent when the initial tissue swelling subsided. He elected not to pursue formalized treatment for the initial injury and noted that it gradually improved. He stated he resumed his cycling training schedule of 200-plus miles per week without pain or limitations at 4 weeks following initial injury despite the soft tissue defect that remained, which was confirmed by visual appearance and palpation. He did, however, confirm that the pain was more noticeable while playing soccer at 12 weeks following initial injury, especially when making any type of cutting or pivoting maneuver several weeks following the injury.

He first presented to the sports medicine clinic seven days following a re-injury to the thigh that occurred 12 months and one day after the initial injury. This re-injury event occurred while also playing soccer. He stated that as he was kicking the ball, a sudden feeling of a “pulling” sensation occurred, which resulted in pain and mild swelling. During examination, the patient described a visible and palpable defect in the proximal anterior thigh. Furthermore, he recalls there was an increase in size of the defect at 12 months following initial injury when re-injury occurred. Visual inspection and evaluation through palpation confirmed the defect. Musculoskeletal ultrasound imaging was utilized to confirm the existence of a defect in the proximal third of the rectus femoris (Figure 1). The palpable defect had presumably filled with fibrotic tissue as suggested by the hyperechoic area that was seen within the musculature as visualized on MSK US. Decreased flexibility along the right lateral thigh was detected that corresponded with painful, latent trigger points in the tensor fasciae latae, iliotibial band and biceps femoris.
Special testing confirmed a positive Ober's test in the involved extremity. Ranges of motion in the knee and hip were measured as being within normal limits and symmetrical. Prone knee flexion measurements were symmetrical in range, but the involved extremity demonstrated a stiffer end-feel. He reported greater difficulty in achieving full prone knee flexion with his affected limb. Hamstring flexibility (as measured using the straight leg raise test) was measured as 80 degrees bilaterally.

**DIFFERENTIAL DIAGNOSIS**

Several possible diagnoses were considered for this patient: contusion of the quadriceps femoris, avulsion fracture of the anterior inferior iliac spine, complete quadriceps femoris rupture, and other specific quadriceps femoris strain. Reaggravation of the initial injury was strongly considered. Further evaluation was completed using visual and manual assessment of anterior and anterior-lateral thigh musculature including the rectus femoris, vastus lateralis, tensor fasciae latae and iliotibial band. Because of the mechanism onset with this episode, the lack of discoloration, and the availability of full range of motion in the involved extremity following the second injury, a quadriceps femoris contusion was deemed an unlikely diagnosis. Furthermore, the patient's pain was located more lateral to the defect along the vastus lateralis and iliotibial band rather than directly over the proximal rectus femoris. The pain corresponded with trigger points along iliotibial band and biceps femoris as opposed to the area directly over the defect where a contusion would have been more likely to have taken place. That a contusion alone would result in the defect that was present in this case was also theorized to be unlikely. It was much more likely to be a tear/re-tear situation given increased size of the defect as reported by the patient.

To rule out avulsion fracture of the anterior inferior iliac spine, the proximal attachment of the rectus femoris was palpated, however, no tenderness to palpation over the proximal attachment of the rectus femoris was noted. Further, while the apparent injury was in the proximal third of the quadriceps femoris, the specific location was distal to this attachment.
point. Therefore, an avulsion fracture involving the anterior inferior iliac spine was inconsistent with the clinical findings.

In the presence of full motion and the patient's capability to demonstrate considerable muscle contraction, a quadriceps femoris rupture was also improbable. This hypothesis was further supported by palpation of muscle belly and area surrounding the defect. In the case of a complete rupture, the defect would have likely been larger in surface area and would have presented with considerable fluid accumulation on the ultrasound image. Lastly, strains of either the vastus medialis or lateralis, though uncommon, were ruled out based upon location and palpation of the defect in the proximal third of the rectus femoris as opposed to the medial or lateral components of the quadriceps femoris musculature. Thus, the most plausible explanation, particularly with the direct visualization of the tissue defect with MSK US (Figure 1), was reinjury of the rectus femoris.

**TREATMENT**

The patient participated in physical therapy for a total of five sessions over the course of six weeks. Treatment consisted of initial soft tissue mobilization with augmented pressure applications to the right quadriceps femoris and anterolateral thigh (Figure 2). This was supplemented by ice massage following instrumented soft tissue mobilization during initial visits to control local hyperemia which resulted from instrumented friction along the proximal quadriceps femoris. As the patient's tolerance increased, these soft tissue techniques were performed during active movements such as knee extensions (Figure 3) and lunges (Figure 4). This progressed into an eccentrically focused home...
exercise program performed three days per week with 30 repetitions per session divided over 3 sets, which incorporated leg extension and leg press exercises (Figure 5). Active quadriceps femoris stretching consisting of prone knee flexion and half-kneeling hip extension with knee on ground was recommended in addition to eccentric exercise to help facilitate the recovery of tissue extensibility. Stretches were performed 3 times and held 30 seconds with gluteal muscle activation incorporated to provide greater stretch and relaxation of tight quadriceps musculature through reciprocal inhibition. Normal range of motion values were sustained throughout treatment course.

**TREATMENT OUTCOMES**

The patient returned to his physician for a follow-up visit at eight weeks following the exacerbation event. Ultrasound imaging was used to document the status of the involved structures before and after physical therapy intervention (Figure 6). The size of the defect, which includes adjacent scar tissue, remained essentially unchanged with dimensions of 1.71 cm and 1.63 cm, respectively. A reduction of hypoechoic zone of surrounding tissue, indicative of edema and tissue damage, is evident in comparing the first and second images. Subjective pain ratings, ultrasound measurements and Lower Extremity Functional Scale (LEFS) scores (20 items scored 0-4 depending upon level of extreme to no difficulty performing task with a ceiling score of 80). These values are presented for both initial and final treatment sessions as referenced in the chart (Figure 7). The patient reported overall improved function, strength and pain levels following exercise program performed three days per week with 30 repetitions per session divided over 3 sets, which incorporated leg extension and leg press exercises (Figure 5). Active quadriceps femoris stretching consisting of prone knee flexion and half-kneeling hip extension with knee on ground was recommended in addition to eccentric exercise to help facilitate the recovery of tissue extensibility. Stretches were performed 3 times and held 30 seconds with gluteal muscle activation incorporated to provide greater stretch and relaxation of tight quadriceps musculature through reciprocal inhibition. Normal range of motion values were sustained throughout treatment course.

**Figure 5.** Instrumented soft tissue mobilization during eccentrically focused machine leg press exercise.

**Figure 6.** Post-treatment diagnostic musculoskeletal ultrasound demonstrating reduction of echogenicity within focal lesion, improved tissue continuity, and reduction of surrounding hypoechoic area.

**Figure 7.** Outcome measures for initial and final treatment sessions indicate improved subjective ratings.

<table>
<thead>
<tr>
<th>Subjective Measure</th>
<th>Initial</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain Rating (with activity)</td>
<td>7/10</td>
<td>2/10</td>
</tr>
<tr>
<td>Global Function Rating</td>
<td>80%</td>
<td>90%</td>
</tr>
<tr>
<td>LEFS Score</td>
<td>67/80</td>
<td>75/80</td>
</tr>
<tr>
<td>Global Rating of Change (2nd &amp; 5th sessions)</td>
<td>+3</td>
<td>+6</td>
</tr>
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six weeks of treatment sessions which incorporated augmented soft-tissue mobilization, eccentric-focused strengthening exercise and stretching. He was able to return to soccer with no return of symptoms and no residual soreness in the affected area.

**DISCUSSION**

A common mechanism of injury for quadriceps femoris muscle strain or tear is a maximal eccentric load to the muscle-tendon unit. The rectus femoris has been described as the most commonly injured muscle of the quadriceps muscle group due to its bi-articulate nature as both the hip and knee are traversed. Eccentric load is distributed throughout the muscle with a combination of hip flexion/knee extension or hip extension/knee flexion. The stress on the rectus femoris is further exaggerated in kicking sports where eccentric load is compounded by muscles counteracting the high velocity forces produced when striking the ball. This mechanism was recognized in the case of this cycling athlete as his injury occurred during soccer.

In a limited number of cases involving chronic symptomatic tears of the rectus femoris, the site of tearing is commonly reported to occur at the reflected head. One of the two heads of the rectus femoris, the reflected head, originates from the acetabulum and attaches distally within the quadriceps femoris tendon. It has been reported to be the most vulnerable to tearing and more commonly involved in rectus femoris injury in magnetic resonance imaging (MRI) studies. The other head of the rectus femoris, the straight head, arises from the anterior inferior iliac spine. The partial tear sustained by the athlete in this case report may have involved the reflected head as suggested by the specific location of the injury.

Non-operative management of partial rectus femoris tears has been supported in the literature. In two isolated cases of proximal avulsion of the rectus femoris in professional football, non-operative treatment resulted in return to play within three to six weeks. Non-operative treatment in these cases incorporated protected weight bearing with crutches, ice, NSAIDs, range of motion exercise, gradual return to resistance training and cardiovascular conditioning which progressed towards running. To the authors knowledge, there are currently no published case studies which have specifically examined the addition of augmented use of Graston® techniques as a part of overall non-operative treatment intervention for rectus femoris tears. Improved range of motion measured by a standard goniometer and quadriceps femoris function based upon subjective ratings using the lower extremity functional scale (LEFS) and progression through quad strengthening program was shown in a patient recovering from a patellar tendon repair following five physical therapy treatment sessions over the period of 1 month. Improved function based upon subjective rating scales and increased tissue healing response has been proposed as the effect created by instrumented soft tissue mobilization resulting in local hyperemia and reduction of scar tissue, possibly enhancing fibroblastic response. Importantly, these techniques are only a part of the treatment plan, which included active motion through strengthening and stretching exercise to aid tissue healing and remodeling and then progression to advanced strengthening with an eccentric emphasis. This case report incorporated all these elements into a rehabilitation program which resulted in marked improvement as demonstrated by improved function and subjective outcomes.

The gold standard for cross-sectional area measurements of muscle size is considered to be MRI. Because of the expense and lack of availability for clinicians, serial imaging to follow muscle and tendon injuries with MRI imaging is cost prohibitive. The widespread interest in the use of MSK US imaging in care and management of patients with musculoskeletal disorders over the last decade has led to improvements in technology and the development of smaller, less expensive machines with improved resolution. MSK US has also been reported to be a cost-effective and highly feasible method, among the imaging modalities, to measure muscle dorso-plantar thickness, medio-lateral width and cross-sectional area of muscles.

Walton et al. showed that MSK US is a reliable alternative to MRI of the quadriceps femoris musculature when determining tissue injury. Their study was performed by taking 10 healthy volunteers and measuring their quadriceps femoris with diagnostic ultrasound and then measuring their quadriceps femoris with MRI. There were no significant differences in the cross sectional area estimates or volume estimates when ultrasound and MRI were compared.
Most musculoskeletal ultrasound is done using “gray scale”, which means images are produced in varying shades of gray, ranging from the extremes of black and white. Each white dot in the image represents a reflected sound wave. Sound waves travel in a similar way that light waves do and therefore the denser a material is, the more reflective it is and the whiter it appears on the screen. Therefore, bones will reflect a significant amount of the sound waves back to the transducer and will produce a white image. Fluids are the least reflective body material and therefore they appear as a black image because the sound waves travel straight through it. Defects in tendons or hematomas usually appear dark or described as hypoechoic. The bones, calcific tendons, or myositis ossificans will appear white or hyperechoic. With training and practice, the practitioner can be able to distinguish normal muscle, tendons, bones, and ligaments from injured ones.

In rare cases, musculoskeletal ultrasound can be used when a standard evaluation is not possible. Such was the case when evaluating a quadriceps femoris tendon tear in an uncooperative patient who presented to an emergency room where ultrasound was used as an alternative to hands-on evaluation. While this may be the exceptional case, further research could make a compelling argument for regular utilization of musculoskeletal ultrasound as part of a thorough evaluation in a clinical setting.

This case report demonstrates utilization of MSK US both before and after rehabilitation to document both differential diagnosis and outcome of treatment interventions. While .08 cm may not be considered a significant difference in terms of the defect size, an improvement in tissue quality was suggested by the ultrasound imaging. This utilization of diagnostic ultrasound in a clinical setting should be recognized as a potential means of identifying tissue lesions or inflammatory processes within healing muscle. In this case report, the post-treatment ultrasound demonstrated that there was not an increased lesion area as a result of augmented soft-tissue technique. Due to this finding, the decreased lesion size may be presumed to be a product of healing. In the presence of a skilled and experienced diagnostic ultrasound user, imaging techniques may be considered a reliable measure of what is shown on screen. More research incorporating diagnostic ultrasound to measure treatment outcomes, however, is needed to support this assumption.

**SUMMARY**

Musculoskeletal ultrasound is a valuable clinical tool for both diagnosis of soft tissue injury and measurement/documentation of changes within injured tissue. The use of musculoskeletal ultrasound allows the clinician to better determine if interventions are effective based upon objective imaging of lesions. Augmented soft tissue techniques (Graston®) were used in conjunction with a typical stretching and exercise/strengthening program, which may have provided an effective environment in which healing appeared to result. In the case of this cycling athlete, MSK US imaging provided visual, objectively measureable evidence that corresponded with the patient’s subjectively reported outcomes and improved function.

**REFERENCES**


CLINICAL COMMENTARY
MANAGEMENT OF BLEEDING AND OPEN WOUNDS IN ATHLETES
Barbara J. Hoogenboom, PT, EdD, SCS, ATC
Danny Smith, PT, DHSc, SCS, OSC, ATC

ABSTRACT
Bleeding or open wounds of the integumentary system occur frequently in athletics. Integumentary wounds vary from minor scrapes, blisters, and small punctures to more serious lacerations and arterial wounds that could threaten the life of the athlete. The Sports physical therapist (PT) must realize that integumentary wounds and subsequent bleeding can occur in many sports, and assessment and care of such trauma is an essential skill. The purpose of this “On the Sidelines” clinical commentary is to review types of integumentary wounds that may occur in sport and their acute management.

Key words: Athletes, bleeding, integument, wounds
Level of Evidence: 5

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INTRODUCTION
Bleeding or open wounds of the integumentary system occur frequently in athletics. Integumentary wounds range from minor scrapes, blisters, and small punctures to more serious lacerations and arterial wounds that could threaten the life of the athlete. The Sports physical therapist (PT) must realize that integumentary wounds and subsequent bleeding can occur in many sports, and assessment and care of such trauma is an essential skill. For example, the skin can be injured by an object travelling at speed (i.e. baseball that is thrown at a high speed, or a shot-put that is thrown at a low speed) or during sports that are classified as high speed collision, due to contact with other athletes, stationary objects, or secondary to an athlete falling or sliding. The sports physical therapist must be prepared to manage any integumentary wound that is encountered on the sideline, using the principles of universal precautions, with thought given to infection control and subsequent wound healing. Prompt and appropriate management of skin lesions and bleeding conditions can decrease the risk of infection, and facilitate safe and expeditious return to sporting events.

The purpose of this clinical commentary is to review types of integumentary wounds that may occur in sport and their acute management.

CLASSIFICATION OF WOUNDS
Arterial wounds
Arterial wounds may be sustained due to lacerations and punctures, and most typically occur due to major trauma. Arterial bleeding, described as pulsatile bleeding, is characterized by blood “spurting” from the body rhythmically by the beating heart. The blood produced by this type of an injury appears bright red, and this situation should be considered a medical emergency. The Sports PT should immediately activate the local emergency care system and should be prepared to take whatever steps are necessary to bring this type of bleeding under control. Arterial bleeding is very difficult to control due to the pressure of the beating heart which pushes blood into the arterial system. Management of acute arterial wounds, which will be discussed later, is extremely time sensitive and requires thorough knowledge of circulatory anatomy.

Venous Wounds
Bleeding of venous origin may also occur due to lacerations and punctures, but unlike the arterial wound, is due to injury of venous structures in the region of the injury. Venous blood appears dark red and flows at a steady rate. (Figure 1) Venous bleeding is much easier to control than arterial bleeding, but can be life threatening in serious situations. Serious situations involving venous bleeding occur when large veins are injured and blood loss is severe.

Capillary Wounds
The most common form of bleeding associated with participation in athletics is capillary bleeding which occurs secondary to an abrasion. (Figure 3) Capillary bleeding is by far the most common skin wound and source of bleeding experienced by the Sports PT.

Figure 1. Example of a superficial laceration on the leg of an athlete, produced by contact with a spiked track shoe.

Figure 2. Example of a puncture wound on the palm of an athlete.
An abrasion most commonly involves the epidermal layer of skin, but in more severe cases may include the removal of the epidermal layer and progression of the wound into the underlying dermal layer. Abra-
sions occur due to friction or scrape which can occur due to the collision of two players or the collision of a player with an object or surface such as a fence, goal-
post, gym floor, or playing field. The injury occurs as force or friction being applied to the soft tissue exceeds the elasticity of the soft tissue, resulting in the super-
ficial layer of skin being removed. This type of bleed-
ing is also commonly referred to as “a strawberry”, “road rash”, “floor or mat burn”, names used to describe the mechanism of injury. Regardless of the mechanism of injury, the outcome is essen-
tially the same, interruption of the integumentary system, damage to the small capillaries, which cre-
ates of an open wound from which blood is lost. This injury results in slow or persistent seeping of blood, sustained over a larger surface area of tissue than the area associated with a puncture wound or abrasion. The size of the wound and the loss of blood are directly proportional to the area of epidermis and dermis that is affected. A bleeding capillary wound is much more painful than arterial or venous wound due to the exposure of multiple small nerve endings.

**WOUND MANAGEMENT**

**Universal Precautions and Preparedness**

When bleeding does occur in athletics, the primary concern of the Sports PT should be self-protection and the prevention of disease transmission. In a study conducted by Jessee et al 4.1% of athletic trainer contacts with high school athletes involved potentially infectious bodily fluids, while the inci-
dence of exposure to these fluids was 12.9% of ath-
lete contacts. They concluded that universal precautions and personal protective equipment should be used in the athletic setting as a matter of course for protection of the health provider and the athlete. The authors of this clinical commentary were unable to find additional incidence data in other levels of sport, but believe that there are a number of steps that should be taken by the Sports PT to protect themselves in all situations. Per-
sonal protective equipment, such as latex or rubber gloves afford protection when controlling bleeding, per-
forming bandaging, and when handling soiled or bloody bandages or instruments. Latex or rubber gloves should be readily available to the Sports PT at all times during the athletic competition, preferably in the pocket of the Sports PT to be accessible at a moment’s notice. Should the Sports PT not have gloves readily available and the athlete suffers an injury resulting in bleeding, time is lost while the Sports PT looks through the sideline kit to locate gloves. This could result in blood loss and loss of precious time in the management of bleeding in the case of severe wounds. In addition to latex or rubber
gloves, sterile gauze four by fours (4 X 4) should also be readily available to assist in covering the wound and achieving hemostasis.

**Arterial Bleeding**

Hemostasis is the goal of treatment of all bleeding wounds.\(^5\) No matter the wound type or etiology, hemostasis is the initial step in providing care to a bleeding athlete. In the most severe example, arterial bleeding should initially be treated by placing direct pressure over the site of the wound with a gloved hand and sterile gauze 4 X 4 if available.\(^1,6\) Any other type of cloth may be used in this emergency situation if no sterile dressings are available to assist in the application of direct pressure. If this technique is sufficient to control the bleeding, the wound should be covered with sterile gauze dressing and a bandage which will continue to apply pressure to the wound. Should the wound resume bleeding, additional direct pressure to the wound with the application of additional dressings and bandages should commence to decrease the loss of blood from the site of the wound. For extremity wounds, elevation above the level of the heart will assist with controlling bleeding. Should these bleeding control techniques fail to control bleeding, pressure over the “pressure point” of the extremity should be utilized.\(^6\) These “pressure points” are located in the upper extremities at the brachial artery located between the biceps and triceps on the inner aspect of the upper arm and for the lower extremities, pressure should be applied to the femoral artery in the femoral triangle. The femoral triangle in the lower extremity is located and the anterior proximal aspect of the hip joint. If the bleeding is unable to be stopped, the final and most extreme measure to control arterial bleeding is the application of a tourniquet. The tourniquet should be applied proximal to the area of the wound.\(^6\) There are many commercial tourniquets available today, however a tourniquet can be fabricated from something as simple as a strip of cloth, a leather or cloth belt, or a piece of rope and a stick of wood or some similar stiff object (used for tightening the rope). It is important to realize the application of a tourniquet is an absolute last resort in the control of arterial bleeding, and it should not be loosened or removed except by trained medical professionals in a controlled environment such as an emergency room or surgery suite. Advanced medical care providers (i.e. EMS personnel) must be notified of the presence of a tourniquet and assurances must be taken that emergency room personnel are aware of the fact that a tourniquet has been placed on the athlete. This is accomplished by informing advanced medical care providers of the presence of a tourniquet or marking with some type of marker change a “T” on the athlete's forehead. This will also serve to inform the hospital personnel that there is a tourniquet in place on the athlete. The tourniquet should never be left in place for an extended period of time secondary to the possibility of tissue necrosis and subsequent loss of limb.\(^6\) Thankfully, very few arterial wounds occur in sport.

**Venous Bleeding**

Control of serious venous blood loss begins with application of direct pressure with a latex gloved hand and sterile gauze, as previously described. The application of a pressure bandage should be considered with the application of sterile gauze directly over the wound followed by the application of a rolled bandage with sufficient pressure to effectively control bleeding.\(^6\) The injured extremity should then be elevated above the level of the heart to utilize gravity to slow the bleeding. If these techniques do not stop the flow of blood, the Sports PT should consider the use of previously described pressure points located at the brachial artery on the medial aspect of the upper arm or the femoral triangle located on the anterior aspect of the hip.

**Lacerations**

During the assessment of the athlete who has sustained a laceration, the Sports PT must initially be concerned with bleeding control and secondarily concerned with disposition of the athlete. The sports PT must decide if use of surgical tape such as Steri-Strips™ (3M, St. Paul, MN) (Figure 5) is sufficient to approximate the edges and maintain closure of the wound or if referral of the athlete to a local hospital or physician's office is necessary to have the wound stitched or stapled closed. When evaluating the wound following injury, once the bleeding is brought under control, the decision as to whether or not to refer the athlete for further care is based on the size and status of the laceration. If the wound “gaps open” or the edges of the wound do not approximate and stick together, the athlete should be referred for...
determine if the use of Dermabond® is within allowable protocol for their use. Dermabond® must be applied to dry skin that has achieved hemostasis. If the use of Dermabond® is acceptable, the Sports PT must carefully cleanse the wound prior to the application of Dermabond® to the edges of the wound. Should Dermabond® be used for wound closure and the wound not be free of bacteria, a serious infection could develop due the closed environment in which bacteria may grow.

**Capillary bleeding**

Abrasions type wounds should be washed with soap and water or a non-cytotoxic cleansing agent. Contaminated abrasions may need to be irrigated under pressure in order to remove foreign particles or debris in the wound bed. Cleansing is important not only to remove contaminants in order to prevent infection, but also to prevent permanent discoloration of the skin known as tattooing. After cleansing, capillary bleeding is controlled through the application of direct pressure with a latex gloved hand and sterile dressing. This type of bleeding is typically not difficult to control with direct pressure. Usually, other methods such as pressure dressings, pressure points, extremity elevation, and application of a tourniquet are not necessary. When hemostasis is achieved, the wound is covered with an application of a topical ointment that contains antibiotics and a local anesthetic. Use of a topical antibiotic is important to prevent wound contamination that may occur due to environmental exposure from surfaces or other athletes. Maintain caution to make certain that the athlete is not allergic to the topical medication. If there are any questions as to the proper utilization of topical antibiotics, check regarding local protocol prior to administering the medication. The Sports PT must also be aware of additional soft tissue damage and subsequent pain that may occur with capillary bleeding. Application of ice and pressure along with elevation of the injured extremity would be appropriate in the management of soft tissue bruising that may occur in this type of injury.

**Healthy wound healing environment**

Finally, regardless of the etiology, the wound must be dressed with an appropriate dressing that allows for a moist healing environment which has been proven to be optimal for epidermal migration.
Optimally, a transparent or semi-permeable film or hydrocolloid is used that provides an anti-microbial barrier while allowing oxygen access to the wound, thus expediting healing.\textsuperscript{3} It is especially important that a moist environment be maintained in the healing process of abrasions, as when they dry out and are allowed to scab they are frequently re-injured by scab removal during sport participation.\textsuperscript{1,2,3}

**CONCLUSION**

In conclusion, the Sports PT may assume the responsibility of management of a number of types of open wounds when providing care on the sidelines of athletic events. The Sports PT must take seriously the use of universal precautions and utilize personal protective equipment, primarily rubber or latex gloves. Sterile dressings and roller bandages should be close by and readily available to hold dressings in place and to apply direct pressure to the wound. Wounds should initially be managed by direct pressure, followed by elevation, pressure dressing and pressure bandage. Should these methods fail to control the bleeding, the Sports PT must consider pressure point application or in extreme cases, the use of a tourniquet. In any case, the Sports PT must be ready to provide appropriate acute wound care and subsequent cleansing and treatment of integumentary lesions.

**REFERENCES**


ABSTRACT

**Purpose/Background:** A reliable and valid method of measuring and monitoring a gymnast's total physical fitness level is needed to assist female gymnasts in achieving healthy, injury-free participation in the sport. The Gymnastics Functional Measurement Tool (GFMT) was previously designed as a field-test to assess physical fitness in female competitive gymnasts. The purpose of this study was to further develop the GFMT by establishing a scoring system for individual test items and to initiate the process of establishing the test-retest reliability and construct validity of the GFMT.

**Methods:** A total of 105 competitive female gymnasts ages 6-18 underwent testing using the GFMT. Fifty of these subjects underwent re-testing one week later in order to assess test-retest reliability. Construct validity was assessed using a simple regression analysis between total GFMT scores and the gymnasts’ competition level to calculate the coefficient of determination ($r^2$). Test-retest reliability was analyzed using Model 1 Intraclass correlation coefficients (ICC). Statistical significance was set at the $p<0.05$ level.

**Results:** The relationship between total GFMT scores and subjects’ current USAG competitive level was found to be good ($r^2 = 0.60$). Reliability testing of the GFMT total score showed good test-retest reliability over a one week period (ICC = 0.97). Test-retest reliability of the individual component items was good (ICC = 0.80-0.92).

**Conclusions:** The results of this study provide initial support for the construct validity and test-retest reliability of the GFMT.

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This study protocol was approved by the Northwestern University Institutional Review Board, Office for the Protection of Research Subjects

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INTRODUCTION
Women’s competitive gymnastics is a multifaceted sport that requires a high level of physical fitness and skill to succeed. Speed,\textsuperscript{1,4} strength,\textsuperscript{2,3,5,6} endurance,\textsuperscript{5} agility,\textsuperscript{7} flexibility,\textsuperscript{3,6-12} balance,\textsuperscript{2,13} and power,\textsuperscript{8,14-16} are all physical abilities that play a role in the success of a competitive gymnast. A gymnast’s physical abilities may also be related to the ability to sustain injury free participation in the sport.\textsuperscript{7,17-19} As such, it is imperative that the coaches, trainers, and therapists involved in the sport be able to monitor an individual gymnast’s physical abilities and overall fitness level as a means of promoting healthy, injury-free participation in the sport.

Traditionally, field-testing has been done in a variety of sports in an effort to measure sport-specific physical abilities.\textsuperscript{20-28} For example, speed, power and agility are physical abilities needed for success in the sport of soccer. Field-tests have been developed in an attempt to quantify each of those physical abilities.\textsuperscript{26,29,30} Some field-tests, such as the hop test\textsuperscript{31} or the agility T-test,\textsuperscript{32} focus on a specific aspect of sport function. Other tests, such as the Functional Movement Screen™ (FMS™),\textsuperscript{33,34} include a battery of individual items designed to assess an athlete’s abilities across multiple aspects of function.

Within the United States Association of Gymnastics (USAG), a system of competitive levels ranging from a low of 4 to a high of 10 is used to rank the skills and abilities of individual gymnasts. To move from one competitive level to the next, a gymnast must achieve a specific all-around score and be able to perform specific skills that increase in difficulty as the competitive level increases. Individual tests for flexibility, strength, endurance, and power have been suggested as useful tools to gauge gymnastic potential.\textsuperscript{35-38} These physical abilities are included in the USAG Talent Opportunity Programs (TOPs) Test, a multi-test battery designed to measure a gymnast’s basic skill in addition to the physical abilities of strength, endurance, power, and flexibility.\textsuperscript{39} Although the TOPs protocol has changed a number of times since its development by William Sands,\textsuperscript{37} it is used primarily with young club gymnasts ages 7-10 years of age to identify competitive potential and aid in the development of the United States competitive gymnastics program. The TOPs was thus not designed to address the needs of gymnasts of all ages or those who compete through high school or collegiate programs. While specialized training is needed to administer the TOPs and the number of people deemed qualified to administer the test is limited, the reliability and validity of the TOPs test have not been reported.

Currently there is not a reliable and valid measurement tool to evaluate the specific physical fitness abilities needed for successful competition in either men’s or women’s gymnastics. Previous studies have examined possible correlations between a gymnast’s level of competition or intensity of training and various singular physical fitness traits.\textsuperscript{3,12,40} Nelson and co-workers\textsuperscript{3} investigated the relationship between gymnasts’ flexibility and strength and varying training intensity levels. The gymnasts at the highest level of training were reported to be the most flexible, had a slender body type, weighed less, and demonstrated higher amounts of both functional and absolute strength especially in the upper body. In 1989, Faria et al\textsuperscript{41} examined the relationship between anthropometric and physical characteristics of male gymnasts and overall competitive performance success. These researchers concluded that the top gymnasts were stronger in both absolute upper body strength and upper body strength relative to body-weight, possessed greater overall flexibility through the hip region, shoulder girdle, and back, and possessed the least percentage of body fat.\textsuperscript{41} Neither of these studies used a standardized measurement tool to determine an overall fitness score or explore the relationship between age or body weight and physical abilities.

Without a reliable and valid field-test for measuring gymnasts’ physical abilities, fitness evaluation and training are often left to the tradition-driven ways of individual coaches. As stated by Sands,\textsuperscript{19} “…. Gymnasts often simply ‘trick’ themselves into shape meaning they perform skills over and over until they acquire the fitness and skill to perform the movement”.\textsuperscript{(p.367)} This may lead to an athlete who is simply fit to do certain skills but who does not have the overall fitness level necessary for prolonged participation in the sport. With the consistent increases in the complexity and difficulty of the gymnastics elements being performed during competition,\textsuperscript{7}
a reliable and valid method of measuring and monitoring gymnasts’s total physical fitness levels is needed to collectively measure the physical abilities of gymnasts and monitor their physical state.

Establishing the reliability and validity of a measurement tool is a multi-step and complex process that must be investigated within the context of the tool’s intended use. Various types of validity must be considered when evaluating a new measurement tool. Construct validity, or the ability of a tool to measure the abstract concept it is intended to evaluate, is one type of validity that must be assessed. Methods of construct validation include convergence and discrimination, factor analysis, the known groups method, criterion validation, and hypothesis testing. Methods related to hypothesis testing are based on the ability of a measurement tool to reflect specific assumptions that form the framework underlying the theoretical basis of the construct. Given that a single study cannot definitively verify a theory, construct validation is considered to be an on-going process.

Various forms of reliability such as intra-rater reliability, inter-reliability and test-test reliability must also be considered when evaluating a measurement tool. Test-retest reliability is used to establish that a tool will obtain the same results across repeated administrations of the same test. Intervals between test administrations must be long enough to avoid the impact of factors such as subject fatigue and learning effects but close enough to avoid true changes in the measured variable.

Overview of the GFMT
The Gymnastics Functional Measurement Tool (GFMT) was developed to assess a gymnast’s overall fitness level while minimizing the impact of gymnastic skill on testing scores.43,44 Identifying fitness deficits to be targeted for improvement as part of a gymnast’s individual training regime may prove useful in injury prevention. As a field-test for female competitive gymnasts of all ages, the GFMT was designed to be carried out by coaches, trainers and therapists using equipment commonly found in any gymnastics gym (club, high school, collegiate, etc.).

Given that successful participation in women’s competitive gymnastics requires a combination of abilities related to flexibility, speed, power, strength, muscular endurance, and balance,1-16 the individual items of the GFMT were developed based on knowledge of these requirements, a review of the literature, and consultation with experts in the field of women’s gymnastics.43,44 The 10 items comprised in the GFMT are summarized in Table 1 and detailed in Appendix I.

<table>
<thead>
<tr>
<th>Item</th>
<th>Targeted Area(s) of Fitness Assessment</th>
<th>Units of Measure for Raw Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Rope Climb Test</td>
<td>Strength and endurance, as well as trunk control</td>
<td>Seconds*</td>
</tr>
<tr>
<td>The Jump Test</td>
<td>Lower extremity power</td>
<td>cm</td>
</tr>
<tr>
<td>The Hanging Pikes Test</td>
<td>Abdominal strength, hip flexor strength, and flexibility as well as grip strength</td>
<td>Number of reps</td>
</tr>
<tr>
<td>The Shoulder Flexibility Test</td>
<td>Shoulder complex flexion flexibility</td>
<td>cm/arm length</td>
</tr>
<tr>
<td>The Agility Test</td>
<td>Speed, endurance, and agility</td>
<td>Seconds</td>
</tr>
<tr>
<td>The Over-grip Pull-up Test</td>
<td>Upper extremity strength and muscular endurance</td>
<td>Number of reps</td>
</tr>
<tr>
<td>The Splits Test</td>
<td>Pelvis and lower extremity flexibility</td>
<td>Sum of cm split clearance/leg length</td>
</tr>
<tr>
<td>The Push-up Test</td>
<td>Shoulder and upper extremity strength</td>
<td>Number of reps</td>
</tr>
<tr>
<td>The 20-Yard Sprint Test</td>
<td>Speed and power</td>
<td>Seconds</td>
</tr>
<tr>
<td>The Handstand Test</td>
<td>Upper extremity strength and endurance as well as balance in a head-down position</td>
<td>Seconds</td>
</tr>
</tbody>
</table>

* Signifies a form component within the final item score

Table 1. Individual Items Comprising the GFMT
The purpose of this study was to continue developing the GFMT by establishing a scoring system for individual test items and initiating the process of establishing test-retest reliability and construct validity. Given the authors’ belief that a gymnast’s total GFMT score would vary based on her current USAG competitive level, construct validity was assessed using the known-groups method of construct validation.

METHODS

Approval for the study was obtained from the Office for the Protection of Research Subjects at Northwestern University. Healthy competitive female gymnasts were recruited from gymnastics clubs throughout the Midwestern and Mid-Atlantic United States. Inclusion criteria required the subjects to be female, between 6 and 18 years of age, and competitive in gymnastics at USAG levels 4 to 10. Exclusion criteria included musculoskeletal pathology currently limiting the gymnast’s ability to train or compete; a history of, or current systemic illnesses including cardiovascular or pulmonary disease; musculoskeletal disease or rheumatoid arthritis; and a lack of informed assent given by the participant or consent given by the parent/legal guardian. A total of 105 subjects participated in the study. Refer to Figure 1 for a flowchart reflecting subjects’ participation in the study.

All testing was performed in the subjects’ home gyms or in a gym familiar to the subject. Subjects did not have prior knowledge or exposure to the specific items composing the GFMT. Each subject provided her own USAG competition level which was recorded by the testers. Prior to testing, subjects completed their regular, coach-directed warm-up routines without regard to the requirements of the GFMT. Given that field-tests composed of multiple items are often administered in stations each consisting of an individual item, subjects were placed into groups of 10 to 12 and moved through each of the 10 stations to complete the GFMT. Data was collected by second year Doctor of Physical Therapy students from Northwestern University and by gymnastics coaches with a minimum of 5 years of coaching experience. In an effort to simulate actual practice patterns, all data collectors were provided with a detailed set of instructions for administering each item on the GFMT but did not undergo any specialized or extensive training. Raw data for each item of the GFMT was recorded in units of measurement that were appropriate for the item tested. Units of measurement for the raw data of each item are listed in Table 1. Subjects were not intentionally masked as to their item scores. Individual GFMT items were completed in the following order to help reduce the effects of regional fatigue: Rope Climb Test, Jump Test, Hanging Pikes Test, Shoulder Flexibility Test, Over-grip Pull-up Test, Splits Test, Push-up Test, 20-yard Sprint Test and Handstand Hold Test. Subjects were given a minimum of 5 to 10 minutes rest between administrations of each item of the GFMT.

From the 105 total subjects, a convenience sample of 50 subjects was chosen to participate in test-retest reliability testing. These 50 subjects were retested with the GFMT one week after initial testing. Test conditions and administration were consistent between the 2 administrations of the GFMT including warm-up and item order. To help ensure that test-retest reliability
rather than intra-rater reliability was assessed, testers administered different items from the GFMT on each of the 2 administration dates.

**STATISTICAL METHODS**

**Development of the Scoring System**
To develop the scoring system for the GFMT, raw scores in the appropriate units of measurement were recorded for each of the individual items on the GFMT. The raw scores for each item were used to calculate the range, mean, and standard deviation for each individual item of the GFMT (n = 105). Data was then transformed to an ordinal scale using the following procedure. In an attempt to reduce the possibility of ceiling and floor effects, 5 percent of the total range of the raw scores was added to the high score of each item and 5 percent was subtracted from the low score of each item. The resulting range of scores for each individual item was then divided by 11 to create a 0 to 10 ordinal scale for each individual item on the GFMT. The ordinal scale for each item was used to create a total GFMT score out of a possible 100 points (10 points for each item). Based on these findings, the scoring for each individual item and for the total GFMT score were finalized and are provided in the GFMT Score Sheet found in Appendix II.

**Test-retest and Construct Validity:**
Test-retest reliability was analyzed using Model 1 Intraclass correlation coefficients (ICC). Although a process of systematic randomization was not employed in the study, a Model 1 ICC was used to reflect the concept that individual items on the GFMT were administered by different testers on each of the 2 test dates. The variance assessed was thus restricted to differences in the subjects' scores in the test-retest design and necessitated the use of a Model 1 ICC.

Given that previous studies had reported a positive relationship between various singular fitness traits and a gymnast's level of competition, it was theorized that the total scores on the GFMT would vary with a gymnast's current competitive level. This was based upon the concept that at each increasing competitive level, a gymnast is required to perform increasingly difficult skills that require a related increase in the gymnast's physical abilities. Construct validity was thus evaluated based on the authors' belief that there would be a direct linear relationship between a gymnast's physical abilities as measured by the GFMT and the gymnast's current level of competition as reflected by the gymnast's USAG level. A simple regression analysis was performed using USAG competitive level to predict total GFMT score. The coefficient of determination \( r^2 \) was used to explore this relationship. Statistical significance was set at the \( p < 0.05 \) level.

**RESULTS**
Of the 148 subjects assessed for eligibility in this study, 105 subjects participated. Forty-three of the recruited subjects were excluded from the study due to recent injury (n = 38) or the lack of a signed informed consent or assent (n = 5). The mean age of participating subjects was 12.64 years with these subjects reporting participation in competitive gymnastics for a mean of 5.4 years. Mean height and weight of the subjects were 149 cm and 42.76 kg, respectively. Subject demographics, categorized by USAG competition level, are summarized in Table 2. Mean GFMT component test raw scores and standard deviations are presented in Table 3.

Raw scores for all items on the GFMT demonstrated a normal distribution with the exception of the Handstand Test, which presented with a right skew. This skew possibly reflects the complexity of this particular activity. The relationships between the subjects' current USAG competitive level and individual component raw scores are presented in Table 4. As indicated in Table 4, several of these relationships were statistically significant, however, \( r^2 \) values demonstrated moderate to poor relationships between USAG competitive level and individual component raw scores (\( r^2 = 0.05-0.47 \)). The relationship between total GFMT scores (out of a possible score of 100) and the subjects' current USAG competitive level was found to be good (\( r^2 = 0.62 \)). Figure 2 demonstrates the relationship between USAG competitive level and total GFMT Scores. To rule out alternative explanations for the relationship between USAG competitive level and total GFMT scores, the relationships between total GFMT scores and age and total GFMT scores and bodyweight were also explored. Statistically significant relationships were identified between total GFMT score and age and between total GFMT score and bodyweight (\( r^2 = 0.13 \)). However, \( r^2 \) values demonstrated a poor relationship between total GFMT score and age (\( r^2 = 0.29 \)) and between total GFMT score and bodyweight (\( r^2 = 0.13 \)).
Table 2. Subject Demographics by Competitive Level.

<table>
<thead>
<tr>
<th>Competition Level</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Subjects</td>
<td>12</td>
<td>9</td>
<td>16</td>
<td>21</td>
<td>11</td>
<td>19</td>
<td>17</td>
</tr>
<tr>
<td>Mean Age in Years (sd)</td>
<td>10.4 (2.3)</td>
<td>9.9 (1.5)</td>
<td>10.7 (1.1)</td>
<td>12.0 (1.6)</td>
<td>13.7 (1.8)</td>
<td>14.6 (1.3)</td>
<td>15.2 (1.8)</td>
</tr>
<tr>
<td>Mean Years Competing</td>
<td>2.6</td>
<td>1.8</td>
<td>4.3</td>
<td>4.1</td>
<td>6.4</td>
<td>7.6</td>
<td>8.2</td>
</tr>
<tr>
<td>Mean Height in cm (sd)</td>
<td>140 (11.0)</td>
<td>137 (8.4)</td>
<td>139 (6.9)</td>
<td>146 (10.9)</td>
<td>154 (3.4)</td>
<td>157 (5.7)</td>
<td>154 (6.2)</td>
</tr>
<tr>
<td>Mean Weight in kg (sd)</td>
<td>33.3 (9.1)</td>
<td>32.3 (4.7)</td>
<td>33.8 (3.9)</td>
<td>39.8 (8.2)</td>
<td>46.2 (9.8)</td>
<td>49.0 (5.8)</td>
<td>50.7 (10.7)</td>
</tr>
</tbody>
</table>

sd = Standard Deviation, cm = Centimeters, kg = Kilograms

Table 3. Mean and Standard Deviation of GFMT Individual Item Scores and GFMT Total Scores (n = 105).

<table>
<thead>
<tr>
<th>Total sample (Levels 4 - 10)</th>
<th>Rope Climb Time (secs)</th>
<th>Vertical Jump Height (cm)</th>
<th>Hanging Pikes (reps)</th>
<th>Shoulder Flexibility (cm/arm length)</th>
<th>Agility (secs)</th>
<th>Pull-ups (reps)</th>
<th>Splits (combined [cm/leg length])</th>
<th>Push-ups (reps)</th>
<th>20 Yard Sprint (secs)</th>
<th>Handstand (secs)</th>
<th>Total GFMT Score (100)</th>
<th>Mean (sd)</th>
<th>Mean (sd)</th>
<th>Mean (sd)</th>
<th>Mean (sd)</th>
<th>Mean (sd)</th>
<th>Mean (sd)</th>
<th>Mean (sd)</th>
<th>Mean (sd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 4 scores</td>
<td>16.64 (6.8)</td>
<td>33.33 (4.9)</td>
<td>11.08 (6.9)</td>
<td>0.67 (0.15)</td>
<td>20.73 (0.9)</td>
<td>5.25 (3.4)</td>
<td>-0.38 (0.27)</td>
<td>18.42 (5.6)</td>
<td>3.74 (0.3)</td>
<td>3.67 (5.6)</td>
<td>30.83 (8.5)</td>
<td>19.00 (3.4)</td>
<td>23.10 (3.2)</td>
<td>23.48 (29.5)</td>
<td>50.38 (15.9)</td>
<td></td>
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<td></td>
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<tr>
<td>Level 5 scores</td>
<td>16.91 (3.8)</td>
<td>31.50 (5.7)</td>
<td>7.67 (9.5)</td>
<td>0.63 (0.13)</td>
<td>20.89 (1.6)</td>
<td>5.11 (4.9)</td>
<td>-0.15 (0.48)</td>
<td>13.22 (7.0)</td>
<td>3.55 (0.3)</td>
<td>3.69 (2.6)</td>
<td>29.78 (12.0)</td>
<td>21.90 (4.3)</td>
<td>23.86 (3.1)</td>
<td>24.30 (29.5)</td>
<td>48.75 (8.3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Level 7 scores</td>
<td>16.35 (5.3)</td>
<td>40.69 (6.6)</td>
<td>17.69 (8.3)</td>
<td>0.80 (0.18)</td>
<td>19.29 (0.7)</td>
<td>8.63 (3.7)</td>
<td>-0.10 (0.35)</td>
<td>26.38 (7.6)</td>
<td>3.37 (0.2)</td>
<td>11.72 (14.6)</td>
<td>47.85 (8.3)</td>
<td>23.30 (3.6)</td>
<td>23.86 (3.1)</td>
<td>24.30 (29.5)</td>
<td>48.75 (8.3)</td>
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<td>Level 8 scores</td>
<td>15.35 (10.0)</td>
<td>42.74 (5.2)</td>
<td>13.14 (9.4)</td>
<td>0.85 (0.23)</td>
<td>19.23 (0.9)</td>
<td>7.52 (4.1)</td>
<td>-0.15 (0.45)</td>
<td>22.95 (9.4)</td>
<td>3.28 (0.2)</td>
<td>11.31 (19.2)</td>
<td>46.71 (10.2)</td>
<td>25.60 (3.9)</td>
<td>25.86 (3.1)</td>
<td>25.86 (29.5)</td>
<td>50.91 (10.5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 9 scores</td>
<td>12.15 (3.2)</td>
<td>44.45 (5.1)</td>
<td>15.73 (8.6)</td>
<td>0.80 (0.28)</td>
<td>18.66 (1.2)</td>
<td>7.00 (2.8)</td>
<td>-0.05 (0.27)</td>
<td>22.45 (8.0)</td>
<td>3.21 (0.2)</td>
<td>15.38 (17.8)</td>
<td>50.91 (10.5)</td>
<td>28.30 (4.8)</td>
<td>28.36 (3.1)</td>
<td>28.36 (29.5)</td>
<td>59.00 (7.9)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 10 scores</td>
<td>11.97 (3.0)</td>
<td>44.42 (3.2)</td>
<td>24.11 (8.0)</td>
<td>0.70 (0.12)</td>
<td>18.24 (0.8)</td>
<td>8.26 (2.4)</td>
<td>-0.02 (0.38)</td>
<td>27.42 (6.9)</td>
<td>3.09 (0.2)</td>
<td>42.38 (31.7)</td>
<td>59.00 (7.9)</td>
<td>31.60 (4.5)</td>
<td>31.66 (3.1)</td>
<td>31.66 (29.5)</td>
<td>71.18 (9.4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sd = Standard Deviation, cm = Centimeters, kg = Kilograms, secs = Seconds, deg = Degrees, reps = Repetitions.

Raw item scores were used to examine the test-retest reliability for each item on the GFMT. Test-retest reliability of total GFMT scores was also determined. Reliability testing of the GFMT total score showed good test-retest reliability over a one week period (ICC = 0.97). Test-retest reliability of the individual component tests was good to excellent (ICC = 0.80-0.92). Reliability coefficients are shown in Table 5. A statistically significant difference (p<0.05) between the first and second test scores was identified for the GFMT Total score and for the following test items: the Hanging Pikes Test, the Vertical Jump Test, and the Splits Test.
DISCUSSION

The GFMT provides the coaches, trainers, and therapists who work with female gymnasts of any age or competitive level with a functional tool designed to assess the unique aspects of fitness that are necessary for safe and effective participation in the sport. Given that the GFMT was developed as a field-test that can be administered without extensive training using equipment readily available in a gymnastics gym, the authors believe that the GFMT can be easily incorporated into any gymnastics program. Identifying fitness deficits that can be targeted as part of a gymnast’s individual training regime may prove useful in injury prevention.

Table 4. Relationship between GFMT Individual Test Raw Score and Composite Score and the Subjects’ Current Competitive Level, Body Weight and Age (n = 105).

<table>
<thead>
<tr>
<th></th>
<th>Rope Climb Component Score</th>
<th>Vertical Jump Height (cm)</th>
<th>Hanging Pikes (reps)</th>
<th>Shoulder Flexibility (cm/arm length)</th>
<th>Agility (secs)</th>
<th>Pull-ups (reps)</th>
<th>Splits (combined cm/leg length)</th>
<th>Push-ups (reps)</th>
<th>20 Yard Sprint (secs)</th>
<th>Handstand (secs)</th>
<th>Total Score (/100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test score vs. Competitive Level</td>
<td>0.27</td>
<td>0.42</td>
<td>0.27</td>
<td>0.05</td>
<td>0.42</td>
<td>0.20</td>
<td>0.09</td>
<td>0.25</td>
<td>0.47</td>
<td>0.38</td>
<td>0.62</td>
</tr>
<tr>
<td>Test score vs. Age</td>
<td>0.14</td>
<td>0.28</td>
<td>0.06</td>
<td>0.38</td>
<td>0.04</td>
<td>0.01</td>
<td>0.10</td>
<td>0.42</td>
<td>0.18</td>
<td>0.29</td>
<td></td>
</tr>
<tr>
<td>Test score vs. Body weight (kg)</td>
<td>0.10</td>
<td>0.26</td>
<td>0.01</td>
<td>0.31</td>
<td>0.00</td>
<td>0.00</td>
<td>0.03</td>
<td>0.32</td>
<td>0.02</td>
<td>0.13</td>
<td></td>
</tr>
</tbody>
</table>

Values expressed in terms of Coefficient of Determination ($r^2$)
* Denotes statistical Significance (p<.05)

DISCUSSION

The GFMT provides the coaches, trainers, and therapists who work with female gymnasts of any age or competitive level with a functional tool designed to assess the unique aspects of fitness that are necessary for safe and effective participation in the sport. Given that the GFMT was developed as a field-test that can be administered without extensive training using equipment readily available in a gymnastics gym, the authors believe that the GFMT can be easily incorporated into any gymnastics program. Identifying fitness deficits that can be targeted as part of a gymnast’s individual training regime may prove useful in injury prevention.

Table 5. Score Means and Standard Deviations for Both Test Days and Intraclass Correlation Coefficients for Test Retest Reliability (n=50).

<table>
<thead>
<tr>
<th></th>
<th>Rope Climb Time (secs)</th>
<th>Vertical Jump Height (cm)</th>
<th>Hanging Pikes (reps)</th>
<th>Shoulder Flexibility (cm/arm length)</th>
<th>Agility (secs)</th>
<th>Pull-ups (reps)</th>
<th>Splits (combined cm/leg length)</th>
<th>Push-ups (reps)</th>
<th>20 Yard Sprint (secs)</th>
<th>Handstand (secs)</th>
<th>Total GFMT Score (/100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Day 1 scores</td>
<td>5.86 (1.9)</td>
<td>40.47 (6.8)</td>
<td>16.84 (8.3)</td>
<td>0.77 (0.2)</td>
<td>19.54 (1.3)</td>
<td>8.32 (4.2)</td>
<td>-0.008 (0.40)</td>
<td>25.2 (9.9)</td>
<td>3.81 (0.2)</td>
<td>21.46 (29.3)</td>
<td>48.54 (15.0)</td>
</tr>
<tr>
<td>Test Day 2 scores</td>
<td>6.61 (2.0)</td>
<td>41.93* (7.1)</td>
<td>19.84* (9.9)</td>
<td>0.79 (0.2)</td>
<td>19.51 (1.2)</td>
<td>8.58 (3.4)</td>
<td>-0.092* (0.36)</td>
<td>26.42 (10.3)</td>
<td>3.82 (0.3)</td>
<td>24.70 (32.5)</td>
<td>51.26* (15.5)</td>
</tr>
<tr>
<td>Test retest reliability ICC</td>
<td>0.80</td>
<td>0.83</td>
<td>0.88</td>
<td>0.92</td>
<td>0.86</td>
<td>0.89</td>
<td>0.91</td>
<td>0.84</td>
<td>0.85</td>
<td>0.92</td>
<td>0.97</td>
</tr>
</tbody>
</table>

* Signifies statistically significant difference from Test Day 1 scores p<0.05

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Raw data collected in this study was used to develop the scoring system for the GFMT. Transformation of the raw data for each individual item to an ordinal scale allowed for a total GFMT score out of a possible 100 points (10 points for each item) and permitted raw data based on a variety of units of measurement to be considered within a total score. As reflected in Appendix I, the raw score for the Rope Climb item reflects both the amount of time needed to complete the climb and the qualitative analysis of the climbing technique used by the gymnast during the climb. Scoring for this item thus reflects a 0 to 5 ordinal scale for time developed using the procedures outlined above as well as a 0 to 5 score for climbing technique as outlined in Appendix I.

The results of this study provide initial support for the construct validity and test-retest reliability of the GFMT. Although construct validity is only one of the many forms of validity to be considered when evaluating a measurement tool,42,46 the relationship between a gymnast's total GFMT score and current USAG competitive level provides support for the concept that GFMT scores will vary based on a gymnast's current competitive level. Examining data from the individual items comprising the GFMT reveals that certain items such as the Jump Test, the Agility Test, and the 20-Yard Sprint Test relate more strongly to a gymnast's current competitive level than items such as the Shoulder Flexibility Test and the Splits Test. Despite the variations in the strength of the relationship between individual items and competitive level, the authors believe that all items on the GFMT must be administered to fully assess a gymnast's fitness across multiple domain areas (strength, flexibility, power, etc.). Maintaining a complete representation of fitness within the GFMT is necessary in order to adequately identify a gymnast's fitness deficits and aid in the development of a fitness program tailored to address individual fitness needs.

The procedures and methods used in this study allowed the researchers to evaluate the GFMT within the context of its intended use as a field-test to assess a gymnast's overall fitness level while minimizing the impact of gymnastic skill on testing scores.43,44 As such, testing was conducted in a manner consistent with the sport in an environment familiar to the individual athletes. Each item on the GFMT was administered at a separate station by different testers to reflect the common practices of field-test administration. Testers were intentionally provided with detailed instructions for administering each item but did not undergo extensive or additional training. Results are therefore felt to reflect the application of the GFMT within the setting for which it was intended to be used.

The intended purpose and use of a measurement tool dictate the relative importance of various forms of reliability. Given that the GFMT was designed as a physical fitness field-test, assessment of test-retest reliability was felt to be essential. The one week interval between test administrations attempted to control for factors such as fatigue or learning effects that may have impacted a gymnast's performance while trying to avoid enough passage of time to permit a true change in a gymnast's overall fitness.

This study was limited by several factors. The total number of participants at any given USAG level ranged from 9 to 21. Increasing these numbers to ≥30 participants at each USAG level may have yielded different results. Although methods such as using physical therapy students and coaches to collect the data may have helped to reflect the use of the GFMT within the context of its intended use, greater methodological control and therefore different results may have been obtained through the use of more stringent techniques such as employing highly trained, researching physical therapists to collect the data. While attempts were made in the test-retest procedures to decrease the possibility of a practice or learning effect, the authors’ recognize that such factors may have impacted score differences between the first and second administrations of the GFMT.

Further research is needed to continue the process of establishing the various types of reliability and validity of the GFMT. The possibility of correlations between total GFMT score and such factors as body composition/percentage of body fat and body mass index must be explored. Future studies should also explore the ability of the GFMT total score and individual item scores to identify a gymnast’s risk for specific injuries and whether the GFMT could be used to help determine if and when an injured gymnast can safely resume high-level training and competition. Finally, since the GFMT was developed exclusively for female gymnasts, a different tool that reflects the demands and specifications of men’s competitive gymnastics should also be developed.
CONCLUSION
Although the process of establishing the reliability and validity of any measurement tool is a complex and lengthy procedure, the results of this study provide initial support for the construct validity and test-retest reliability of the GFMT.

REFERENCES


# APPENDIX 1: INSTRUCTIONS FOR ADMINISTRATION OF THE GFMT.

<table>
<thead>
<tr>
<th>Item</th>
<th>Procedure</th>
<th>Comments and Illustrations</th>
</tr>
</thead>
</table>
| **Rope Climb Test** | - The gymnast starts in a seated pike (legs together) position directly beneath a vertical rope with her hands on a “starting line” marked on the rope.  
- The test and timing begins when the gymnast leaves the floor. The gymnast must attempt to maintain a pike position at a horizontal level throughout the test.  
- The tester stops timing when the gymnast touches a 15-foot mark measured from the “starting line” or is unable to continue climbing.  
- Scoring is based on the gymnast’s ability to complete the climb, the amount of time to perform the climb, climbing technique (hand to hand or hand over hand) and hip and leg position maintained during the climb.  
  ♦ The pike position must be held to the side of the rope; the gymnast may not straddle the rope.  
  ♦ The rope can be held by an assistant for stability throughout the test if the gymnast requests.  
  ♦ Hand over hand climb – 90 degree hip flexion – 5 points  
  ♦ Hand over hand climb – hips not maintained at 90 degree flexion – 4 points  
  ♦ Hand over hand climb with help of legs – 3 points  
  ♦ Hand to hand climb, with help from legs – 2 points  
  ♦ Unable to complete 15 feet – 1 point  
  ♦ Unable to climb – 0 points | ![Image 1]  
| **The Jump Test** | - Before the Jump Test, the gymnast places a generous amount of chalk on her fingers so that accurate measurements can be made.  
- The gymnast stands with her dominant side to the wall (but not against it) and perform a vertical jump using both legs, placing a chalk mark on the wall at the top of her jump.  
- The jump must be performed by pushing off from both lower extremities equally.  
- Following the jump, standing flat-footed with the dominant side to the wall, the gymnast reaches with the chalked hand directly overhead, touching the wall and leaving a mark of chalk at the highest point.  
- Using a tape measure, the examiner measures and records the distance between the tops of the two chalk marks in a line perpendicular to the floor to the nearest centimeter. | ![Image 2]  
| **The Hanging Pikes Test** | - The gymnast begins the test from a dead hang, without the use of handgrips, on a standard horizontal bar.  
- The gymnast is then asked to flex at the hips with legs together and knees extended and attempt to touch her toes to the bar.  
- Between pike attempts, the gymnasts must be in a momentary dead hang to prevent the use of momentum to gain an advantage for her next pike-up.  
- The test score is based on the number of pikes completed. | ![Image 3]  
| **The Shoulder Flexibility Test** | - Prior to shoulder flexibility testing, the gymnast’s arm length is measured from the tip of the acromion process to a ½ inch wooden dowel grasped by both hands while holding her shoulders flexed to 90 degrees.  
- For testing, the gymnast lies prone on a firm floor with her chin and nose touching the floor.  
- Both arms are held parallel to the body with the shoulders flexed to 180 degrees.  
- The gymnast grasps the 1/2-inch dowel with an overhand grip and tips of her thumbs touching.  
- The gymnast is asked to maximally flex her shoulders while maintaining her wrists in a neutral position, elbows extended and her nose and chin in contact with the floor.  
- The wooden dowel must be kept parallel to the floor.  
- Once the gymnast has raised her arms to their maximum height, the distance from the dowel, where her thumbs are touching, to the floor is measured and recorded to the nearest ½ centimeter using a rigid meter stick.  
- The gymnast must hold this position long enough to record the measurement.  
- The Shoulder Flexibility Test raw score is calculated by dividing the dowel height attained by the length of the athlete’s arm. | ![Image 4]
The Agility Test
- Two 6-inch cones are placed diagonally at the corners of a 12m x 12m gymnastics competition floor.
- The gymnast starts standing in one corner of the floor in front of the cone with her feet together as if she were preparing for a tumbling pass.
- When ready, the gymnast is instructed to sprint across the diagonal length of the floor, decelerate, touch the 6-inch cone and then turn around and repeat the run for a total of five passes ending in the corner opposite from where she started.
- Timing starts as soon as the gymnast lifts a foot from the standing position.
- Timing is stopped when any part of the gymnast’s torso crosses over the finish line, which is an imaginary vertical plane from the corner of the floor.
- Time is recorded with a stopwatch to the nearest hundredth of a second.

The Over-grip Pull-up Test
- The gymnast performs pull-ups starting in a hanging position from the standard horizontal bar with an overhand grip and hips and knees flexed to 90 degrees. Gymnastics grips cannot be used.
- A 16-inch length of 1-inch x 4-inch wood is placed on the thighs, at the hip.
- The gymnast then completes as many pull-ups as possible while maintaining the starting lower extremity position.
- A complete pull-up is defined as starting in a full hanging position (elbows extended) and raising the chin so that it clears the horizontal bar completely.
- A pull-up does not count if the chin does not clear the bar, if the gymnast does not start in a fully extended (elbow) position or if the block of wood falls.
- The test can continue as long as the grip is maintained and the evaluator replaces the block of wood.
- The tester records the total number of completed pull-ups for scoring.
- The test will be terminated after 3 unsuccessful attempts or if the gymnast leaves the bar.

The Splits Tests
- Performance of the Splits Test involves left, right, and middle split measurement.
- Left/Right Split: Split testing will be carried out on the left and the right leg following the same procedure.
  - The left split is done in a position in which the left hip is flexed maximally and the right hip is extended maximally.
  - Before testing, the length of the gymnast’s dominant leg is measured from the anterior superior iliac spine to a point on the anterior surface of the ankle in between the lateral and medial malleoli.
  - During both left and right splits testing, the gymnast places the anterior aspect of her trailing leg’s tibia up against a wall in a vertical position to maintain the hip and pelvis in a neutral position.
  - She is then instructed to slide her lead foot out into a split position.
  - Her back must be in a vertical position and hips and shoulders must be square or parallel to the wall.
  - The gymnast is allowed to use parallettes on the left and right for support and to help maintain the proper test position.
  - This position ensures the pelvis is in a standardized neutral position.
  - The measurement is taken between the highest point of clearance in the perineal area and the floor.
  - One individual can be used to ensure the trailing leg is maintained in a vertical position by holding it in place if needed.
  - Split measurement is made from the posterior aspect of the gymnast.
  - A rigid centimeter ruler is held against the gymnast’s sacrum to measure the distance between the highest point of clearance in the perineal area and the floor to the nearest centimeter. If the gymnast is unable to perform the split completely to the floor, the measurement is referred to as a negative (-) centimeter measurement.
  - If the gymnast can achieve full contact during the split, an over-split should be performed.
    - The over-split involves an assistant passively flexing the lead hip while the gymnast maintains a neutral pelvis and extended knee position.
    - The hip is flexed until the gymnast says, “stop” or until the pelvis is lifted from the floor. The height from the posterior aspect of the heel to the floor is measured and recorded in cm.
    - The over-split measurement should be referred to as positive (+) centimeter measurement.
- Middle split testing involves the use of a straight line on the floor.
  - The gymnast is instructed to start the test in a standing position with her heels on the line and feet perpendicular to it.
  - She is then instructed to slide into a middle split position (both hips abducted maximally) keeping her legs parallel to or on the line.
  - The gymnast must lean forward and place her chest on the ground in order to obtain the lowest split position.
  - Once the correct testing position has been obtained, a measurement is taken from the point where the inguinal ligament crosses the ischial line and the floor.
  - If a gymnast is in full contact with the floor during correct performance of the middle split, an over split may be carried out and measured in the same manner described for the left and right splits.
  - The gymnast’s dominant lower extremity will be used for over-split measurements.
  - The positive or negative angles calculated from the left, right and middle are then added to give a final split score.
- The Splits Test raw score will be determined by dividing left, right and middle split perineal height (negative value) or the heel height in the case of an oversplit (positive value) measurement by the leg length and adding the values.
<table>
<thead>
<tr>
<th><strong>The Push-up Test</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- The gymnast starts with her hands shoulder width apart on a low beam.</td>
</tr>
<tr>
<td>- The gymnast's thumbs are placed directly under the shoulders and the elbows positioned away from her side.</td>
</tr>
<tr>
<td>- The gymnast's feet are to be placed together on a panel mat of the same height as the beam.</td>
</tr>
<tr>
<td>- The push-up is then performed with the body in a straight, horizontal position.</td>
</tr>
<tr>
<td>- The gymnast will lower herself until she touches a 1-inch high block placed directly under her chest.</td>
</tr>
<tr>
<td>- Following the chest-to-block contact, the gymnast must extend the elbows until they are locked.</td>
</tr>
<tr>
<td>- The slowest cadence allowed for the push-up is 1 second up and 1 second down.</td>
</tr>
<tr>
<td>- The gymnast should perform as many push-ups as possible. Push-ups do not count if the gymnast fails to reach the block of wood or if she does not fully extend her elbows; however, the test can still proceed.</td>
</tr>
<tr>
<td>- The test score is based on the total number of properly completed push-ups.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>The 20-Yard Sprint Test</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- The sprint test should be performed on a vault runway. Sufficient space must be given past the finish line to ensure that the gymnast is able to slow down.</td>
</tr>
<tr>
<td>- The gymnast begins standing with her feet together.</td>
</tr>
<tr>
<td>- The time begins as soon as the gymnast's left or right foot leaves the floor and is stopped when any part of the gymnast's torso crosses the finish line.</td>
</tr>
<tr>
<td>- Time is recorded with a stopwatch to the nearest hundredth of a second. One trial is allowed.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>The Handstand Test</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- The gymnast starts the handstand with hands at a comfortable distance apart on a low beam.</td>
</tr>
<tr>
<td>- A handstand position, which is defined as any position in which the gymnast’s total bodyweight is supported entirely by the hands, can be accomplished any way the gymnast wishes.</td>
</tr>
<tr>
<td>- Timing begins when the gymnast’s feet leave the ground, and timing stops when any part of the gymnast’s body (other than the hands) touches the beam or the floor or if either of her hands moves from their original position.</td>
</tr>
<tr>
<td>- Time is recorded with a stopwatch to the nearest tenth of a second.</td>
</tr>
<tr>
<td>- The participant is given two trials for this test and her longest time will be used for scoring.</td>
</tr>
</tbody>
</table>
### Gymnastics Functional Measurement Tool (GFMT)

#### Score Sheet

<table>
<thead>
<tr>
<th>Subject ID</th>
<th>Level</th>
<th>Date</th>
<th><strong>TEST SCORE /10</strong></th>
</tr>
</thead>
</table>

*Any physical symptoms must be reported to the coach or test administrator and be documented*

1. **Rope Climb:** Testing Muscular strength and endurance

   a. **Form**
      i. Hand over hand climb – 90 degree hip flexion 5 pts
      ii. Hand over hand climb – hips not maintained at 90 degree flexion 4 pts
      iii. Hand over hand climb with help of legs 3 pts
      iv. Hand to hand climb, with help from legs 2 pts
      v. Unable to complete 1 pts
      vi. Unable to climb 0 pts

   b. **Time**
      i. 0-10 seconds = 5 points, 10.1-12 seconds = 4 points, 12.1 -14 seconds = 3 points, 14.1-16 seconds = 2 points, 16.1 seconds – 18 seconds = 1 point, > 18 seconds = 0 points

   **Symptoms and comments***

2. **Jump Test:** Testing power

   a. Difference in the distance between static stand and reach height and maximal height achieved with a vertical counter movement jump.

      i. Jump height in cm
         1. (< 26.5cm=0 pts, 26.5-30.9cm=1 pts, 31-34.4cm=2 pts, 34.5-37.9cm=3 pts, 38-41.4cm=4 pts, 41.5-44.9cm=5 pts, 45-48.4cm=6 pts, 48.5-51.9cm=7 pts, 52-55.4cm=8 pts, 55.5-58.9cm=9 pts, >59cm=10 pts)

   **Symptoms and comments***

3. **Hanging Pikes:** Testing Muscular strength and endurance

   a. Number of pikes achieved to touch the bar

      i. Number of completed Pikes
         1. 1-10 Score: (0 = 0 pts, 1-4=1, 5-8=2, 9-12=3, 13-16=4, 17-20 =5, 21-24 = 6, 25-28=7, 29-32=8, 33-36 = 9, >36 =10)

   **Symptoms and comments***

4. **Shoulder Flexibility:** Testing Flexibility

   a. Arm length (Acromion process to wooden rod) cm

   b. Distance From Floor cm

      i. 0-10 Score: (distance from floor/arm length)
         1. (<3.49=0 pts, 0.35-0.46 = 1 pts, 0.461-0.57 = 2 pts, 0.571-0.68 = 3 pts, 0/681-0.79 = 4 pts, 0.791-0.90 = 5 pts, 0.91-1.01 = 6 pts, 1.011-1.12 = 7 pts, 1.121-1.23 = 8 pts, 1.231-1.25=9 pts, >1.25=10 pts)

   **Symptoms and comments***

5. **Agility Sprint:** Testing Speed, endurance and agility

   a. **Time**

      i. 0-10 Score:
         1. (>22 seconds = 0 pts, 22-21.5 seconds =1 pts, 21.51-21.0 seconds = 2 pts, 21.01-20.5 seconds = 3 pts, 20.51-20 seconds =4 pts, 20.01-19.5 seconds =5 pts, 19.51-19.0 seconds =6 pts, 19.01-18.5 seconds =7 pts, 18.51-18.01 seconds =8 pts, 18-17.5 seconds =9 pts, <17.5 seconds =10 pts)

   **Symptoms and comments***
6. **Over-grip Pull-ups**: Testing Muscular strength and endurance **TEST SCORE /10**
   a. Number of completed Chin-ups __________
      i. 0-10 Score:
         1. (0=0 pts, 1-2=1 pts, 3-4=2 pts, 5-6=3 pts, 7-8=4 pts, 9-10=5 pts, 11-12=6 pts, 13-14=7 pts, 15-16=8 pts, 17-18=9 pts, >18=10 pts)
      Symptoms and comments*

7. **Split Test: L, R, and Middle**: Testing Flexibility **TEST SCORE /10**
   a. Score will be combination of Distances from the floor for all three splits (*“*“=standard split, “+”=over-split)
      i. Leg Length (cm)  
         L ______  R ______
         cm/leglength ______
         1. L split (-) ______ cm Over split (+) ______ cm Raw  
            cm/leglength ______
         2. R split (-) ______ cm Over split (+) ______ cm Raw  
            cm/leglength ______
         3. Middle split (-) ______ cm Over split (+) ______ cm Raw  
            cm/leglength ______
      ii. 0-10 Score: (Sum of all 3 raw scores) < -0.90 = 0 pts, (-)0.899-(-)0.700 = 1 pts, (-)0.699-(-)0.500 = 2 pts, (-)0.499-(-)0.300 = 3 pts, (-)0.299-(-)0.100 = 4, (-)0.099-1.0 = 5 pts, (+)1.01+(+)3.00 = 6 pts, (+)3.01+(+)5.00 = 7 pts, (+)5.01+(+)7.00 = 8 pts, (+)7.01-9.00 = 9 pts, > (+)9.01 = 10 pts
      Symptoms and comments*

8. **Push-up Test**: Testing Muscular strength and endurance **TEST SCORE /10**
   a. Number of completed Push-ups __________
      i. 0-10 Score: (0=0 pts, 1-5=1 pts, 6-10=2 pts, 11-15=3 pts, 16-20=4 pts, 21-25=5 pts, 26-30=6 pts, 31-35=7 pts, 36-40=8 pts, 41-45=9 pts, 45 >= 10 pts)
      Symptoms and comments*

9. **20 Yard Sprint**: Testing Speed **TEST SCORE /10**
   a. Time
      i. 0-10 Score: >4.3 seconds= 0, 4.29-4.14= 1 pts, 4.13-3.98= 2 pts, 3.97-3.83= 3 pts, 3.82-3.67= 4 pts, 3.66-3.52= 5 pts, 3.51-3.36= 6 pts, 3.35-3.21= 7 pts, 3.20-3.05= 8 pts, 3.04-2.91= 9 pts, <2.90=10 pts
      Symptoms and comments*

10. **Handstand Hold**: Testing Muscular endurance and balance **TEST SCORE /10**
    a. Best time with 2 attempts
       i. Time held trial #1 __________  Time held trial #2 __________
          1. 0-10 Score: (0=0 pts, 1-7 seconds =1 pts, 8-15=2 pts, 16-23=3 pts, 24-31=4 pts, 32-39=5 pts, 40-47=6 pts, 48-55=7 pts, 56-63=8 pts, 64-71=9 pts, >71=10 pts)
          Symptoms and comments*

**TOTAL GFMT TEST SCORE /100**
ABSTRACT

Background: Although upper extremity (UE) closed kinetic chain (CKC) exercises have become commonplace in most rehabilitation programs, a clinically meaningful UE CKC functional test of unilateral ability has continued to be elusive.

Objectives: To examine reliability of the Upper Quarter Y-Balance Test (UQYBT), evaluate the effects of arm dominance on UQYBT performance, and to determine how the UQYBT is related to specific components of the test (trunk rotation, core stability and UE function and performance) in a college-aged population.

Methods: A sample of healthy college students performed the UQYBT and a series of 6 additional dynamic tests designed to assess trunk rotation, core stability, and UE performance. The relationship of these tests compared to the UQYBT was assessed. The effect of upper limb dominance for the UQYBT was also explored. Finally, test re-test reliability was established for the UQYBT.

Results: Thirty subjects (24 males, 6 females, mean ages 19.5 ± 1.2 and 18.8 ± 0.8 years) were assessed during the study. The test re-test reliability was excellent for UQYBT measurements (intraclass correlation coefficient > 0.9). A significant (p <0.05) fair to moderate association was observed between the UQYBT and several core stability and UE functional tests. There was no significant difference in UQYBT performance between dominant and non-dominant limbs.

Discussion: The UQYBT is a reliable UE CKC test that can be used to assess unilateral UE function in a closed chain manner. The UQYBT appears to be most related to dynamic tests involving core stability and UE performance. Similarity on the UQYBT between dominant and non-dominant limbs indicates that performance on this test using a non-injured UE may serve as a reasonable measure for “normal” when testing an injured UE. Future research is needed to determine the clinical applicability of the UQYBT.

Level of Evidence: 2b

Key Words: upper extremity functional testing, Upper quarter Y-Balance test
INTRODUCTION

Over a decade ago, Goldbeck and Davies highlighted the need for reliable and clinically relevant upper extremity (UE) functional testing as they reported reliability of the Closed Kinetic Chain UE Stability Test (CKCUEST).\(^1\) Over a decade later, the CKCUEST remains the only dynamic closed kinetic chain (CKC) test described in the literature to identify deficits in the UE.\(^1\) Because the CKCUEST essentially requires both UEs to function simultaneously, the primary limitation of this test is the inability to differentiate performance for a single limb. Therefore, a limb to limb comparison is not possible with the CKCUEST. A clinically viable and meaningful UE functional test has continued to be elusive.

For theoretically positive reasons, UE CKC exercises have become commonplace in most rehabilitation programs and have been described abundantly in the literature.\(^2\)-\(^{13}\) Proposed benefits of these exercises include increased shoulder stability and proprioception. Inclusion of CKC exercises may also add specificity of training for many sports such as wrestling and football. Despite the general agreement that these exercises are beneficial, there is no universally accepted clinical assessment of upper body closed-chain ability.\(^1,6,14,16\)

Tests such as the push-up test\(^{14,17,18}\) are simple and can be used to assess UE function in a closed chain manner. However, a limitation of this type of test may be the inability to sufficiently assess the upper quarter relevant to many sporting activities, because they do not require the subject to move beyond a limited base of support. Similarly, tests of the upper quarter, such as planks and side bridging are purely static tests, which require no dynamic movement of the UE.\(^{14,15,19}\)

Tests and measures are an essential prerequisite for the development of rehabilitation and training programs.\(^7,10,14\) A well designed assessment gauges a person’s ability and should provide a measurement that does not require extensive interpretation.\(^15\) Because the body operates as a dynamic unit in sports and activities of daily life, isolated clinical assessments of muscle strength and joint mobility do not adequately provide the information needed to assess functional ability or performance.\(^8\) CKC assessments of the UE have been appropriately described as testing the entire “upper quarter”.\(^{15,20}\) Testing of the core and extremities as quadrants can be an efficient and comprehensive method to identify performance, strength, or mobility deficits in the body region being tested.\(^{15,20}\)

The upper quarter Y-balance test (UQYBT) has been proposed as a CKC assessment of upper quarter mobility and stability using a functional testing device (Figure 1).\(^{15,20}\) The assessment is performed with the subject stabilizing his or her body weight with the upper extremity being tested while performing maximal reaching in three directions. Recently, Gorman and colleagues reported good reliability using the UQYBT to measure upper quarter performance.\(^{20}\) A similar test of the lower quarter has been shown to be reliable\(^{21}\) with the ability to predict lower extremity injury in high school basketball players.\(^{22}\) It is possible that the UQYBT may provide similar information regarding performance, strength, and mobility deficits of the upper quarter.

Because of the limited knowledge regarding the UQYBT, the primary purpose of this study was to explore several objectives related to the use of the UQYBT. The first objective was to examine reliability of the UQYBT in a college-aged population. The second objective was

Figure 1. Upper Quarter Y-Balance Test - Direction of reach is named relative to the stationary upper extremity. A. Medial Reach Direction, B. Superior Lateral Reach Direction, C. Inferior Lateral Reach Direction.
to determine how the UQYBT related to specific components of the test (primarily trunk rotation, core stability and UE function and performance). The final objective was to evaluate the effects of arm dominance on performance on the UQYBT, which might assist the clinician in interpreting the results of an injured UE relative to the uninjured UE for an individual patient.

MATERIALS AND METHODS

Design and Setting
A convenience sample of thirty healthy, college-aged subjects was recruited from the United States Military Academy at West Point. Exclusion criteria included any UE or spine pain or injury within the previous 6 months, history of shoulder surgery, or current illness or disease process affecting physical performance. Subjects were provided written and verbal explanation of the testing procedures and provided written informed consent prior to testing. The Institutional Review Board at Keller Army Community Hospital approved the study protocol.

Procedures and Protocols
Primary testing was completed in one session for each subject. Subjects completed a general information questionnaire, the Shoulder Pain and Disability Index (SPADI), and the Disability of the Arm, Shoulder, and Hand (DASH) outcome measure to establish general health, UE dominance (defined as the arm preferred for throwing), and overall shoulder ability. Descriptive data measured for all subjects included age, weight, height, upper limb length, hand length, and torso length. Army Physical Fitness Test (APFT) 2-minute push-up and 2-minute sit-up scores were also recorded.

Upper limb length was measured with the shoulder abducted to 90 degrees with the elbow extended and the wrist and hand in neutral. The measurements were taken from the spinous process of C7 to the tip of the longest digit. Torso length was measured from the spinous process of C7 to a horizontal line corresponding to the iliac crest height. Hand length was measured from the distal wrist crease to the tip of the longest digit.

The Upper Quarter Y-Balance Test (UQYBT) and a series of 6 additional dynamic tests were assessed in addition to shoulder active range of motion (AROM) and isometric strength testing. The sequence of testing order was randomized into 3 testing sequences to mitigate an order effect. The subjects rested for two minutes between trials of dynamic tests to prevent effects of fatigue. Standardized instructions and demonstrations of the tests were provided to subjects prior to each test.

UQYBT
The UQYBT was performed as suggested by previous authors. While maintaining a pushup position with the feet no more than twelve inches apart, the subject performed maximal effort reaches with the free hand in three directions (medial, superolateral, and inferolateral) named in relation to the stationary hand (Figure 1). The distance reached in each direction was recorded. Each subject was allowed 3 practice trials prior to testing. The average of 3 trials was used for analysis. The sum of the 3 reach directions was calculated for a total excursion score. To normalize for limb length, a composite score was calculated taking the total excursion distance and dividing it by 3 times the upper limb length.

Closed Kinetic Chain Upper Extremity Stability Test
The CKCUEST has been described as a reliable clinical tool allowing functional assessment of a subject's UE in a CKC. The CKCUEST begins in the traditional push-up position with the hands placed just inside athletic tape markers placed 36 inches apart. During the CKCUEST, subjects reached with alternating hands across their body to touch the athletic tape under the opposing hand. The number of cross-body touches performed in 15 seconds was recorded. The average of 3 trials was used for analysis.

Shoulder Active Range of Motion and Isometric Strength Testing
Shoulder AROM was measured for flexion, abduction, internal rotation and external rotation using a standard goniometer. Shoulder isometric strength testing was measured using a handheld dynamometer (MODEL #01163, Lafayette Instrument Company, Lafayette, IN) in an upright-seated position for flexion, abduction, internal and external rotation, as well as internal and external rotation at 45 degrees of abduction in supine. The average of 3 trials was used for analysis. Intrarater reliability values in this study for hand-held dynamometer isometric testing ranged from good to excellent (ICC = 0.86 left shoulder IR to ICC = 0.98 right shoulder flexion).
Shoulder Mobility Reach Test
The Shoulder Mobility Reach Test (SMRT) assesses combined extension, internal rotation and adduction on one shoulder while simultaneously assessing combined flexion, external rotation, and abduction in the other. To perform the SMRT the subjects reached as far as possible behind their neck with one hand, while reaching behind the back with the opposite hand. The distance between the hands was recorded. The SMRT was intended to evaluate thoracic spine and scapular mobility as well as actual shoulder motion. The average of 3 trials was used for analysis. SMRT intrarater reliability in this study was the same for both sides (ICC = 0.99).

Trunk Rotation Test
Side-lying trunk rotation measurements (STRM) were conducted as described by Iveson et al. The subject was positioned side-lying with hips and knees bent to 90 degrees (90/90 position). The subjects rotated their trunk back onto the treatment table posteriorly to approximate the scapulae to the table. Measurements for this study were taken using a digital inclinometer (Model: 12-1057, Baseline, Elmsford, NY) positioned across the medial clavicles. The average of 3 trials was used for analysis. Intrarater reliability for the STRM in this study was similar for right and left rotation (ICC = 0.94 left, ICC = 0.95 right).

Lateral Trunk Endurance Test (Side Bridge)
The Lateral Trunk Endurance Test (LTET) was included to assess the endurance of the shoulder and lateral trunk musculature. The subjects were positioned side-lying with their legs extended. The top foot was placed in front of the lower foot for support and the free hand was placed on the shoulder of the stance limb with the arm across the chest. Subjects lifted their hips off the surface to maintain a straight line over their body while supporting themselves with the stance limb and the sides of the feet. The test was terminated when the subject was no longer able to maintain position after one warning or 240 seconds (actual test not to exceed 240 seconds).

Trunk Extensor Endurance Test
The Trunk Extensor Endurance Test was used to assess the endurance of the trunk extensor muscles. Subjects were positioned prone with their torso off the edge of a treatment table/plinth. The anterior superior iliac spine (ASIS) was positioned as close to the edge of the plinth as possible but still supported by the plinth. A 6" foam bolster was placed under subjects’ ankles for comfort and 2 padded belts were used to secure the subject at the mid-thigh and mid-leg. Subjects were required to maintain a horizontal position of the torso for as long as possible. The test was terminated when the subject was unable to maintain position after one warning or 240 seconds (actual test not to exceed 240 seconds).

Trunk Flexor Endurance Test
The Trunk Flexor Endurance Test was used to assess the endurance of the trunk and hip flexor muscles. Subjects were placed in a sit-up position on a treatment table/plinth. A padded belt was used to secure the subject at the proximal ankles. Subjects were required to maintain a 45 degree flexed position of the trunk for as long as possible. The test was terminated when the subject was unable to maintain position after one warning or 240 seconds (actual test not to exceed 240 seconds).

Reliability
To assess test re-test reliability of the UQYBT, half of the subjects (n = 15) were contacted for retesting a minimum of 2 weeks following the initial assessment. Testing procedures mirrored those during initial testing. To be included in this portion, subjects had to report no musculoskeletal injury since the initial testing and that general health was unchanged.

Statistical Analysis
Descriptive statistics were calculated including means, standard deviations, and 95% confidence intervals (CI) for all tests and measures. Limb Symmetry Index (LSI) was calculated using the furthest distance reached on the UQYBT as the reference limb (i.e., percentage of the lesser distance reached divided by the furthest distance reached). Test re-test reliability of the UQYBT was determined using the intraclass correlation coefficient (ICC) statistic. The association between the various performance tests and the UQYBT scores were analyzed using the Pearson Correlation. Potential differences between dominant UE and non-dominant UE performance on the UQYBT were assessed using the independent t-Test.
Results
 Thirty subjects (24 males, 6 females, mean ages 19.5 ± 1.2 and 18.8 ± 0.8 years; mean height 174.4 cm ± 4.9 and 164.8 cm ± 5.3; mean weight 73.9 kg ± 6.0 and 56.3 kg ± 7.5; mean upper limb length 89.5 cm ± 2.9 and 82.4 cm ± 2.0) were assessed during the study. No subject reported any UE disability on the SPADI or DASH questionnaires. Descriptive variables and demographic data are presented in Table 1.

Reliability
 Thirteen of the fifteen subjects contacted were retested on the UQYBT an average of 28 days following initial testing (range 19–47 days). One subject was unable to return due to scheduling conflicts and another reported having injured his shoulder two weeks prior and was therefore excluded from the reliability analysis. The UQYBT test re-test reliability values were similar for both dominant (ICC = 0.91) and non-dominant (ICC = 0.92) UE measurements.

Performance Test Correlations
 There was a significant relationship observed between the UQYBT and core stability measures (i.e., Dominant side LTET; p = 0.04, r = 0.38; Non-dominant LTET; p = 0.01, r = 0.45) and UE CKC performance measures (i.e., CKCUEST p = 0.01, r = 0.49 and APFT pushups p = 0.02, r = 0.41) (Table 2). There was not a significant relationship observed between the UQYBT and measures of trunk rotation, trunk flexor and extensor endurance tests, APFT sit-ups, shoulder AROM, or shoulder isometric strength.

Limb Dominance and Limb Symmetry Index
 Reach distances for the medial, superolateral, and inferolateral directions, the total excursion, and the

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### Table 1. Demographics.

<table>
<thead>
<tr>
<th></th>
<th>Males (N = 24)</th>
<th>Females (N = 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>19.5 (1.2)</td>
<td>18.8 (0.8)</td>
</tr>
<tr>
<td>Height (cm)*</td>
<td>174.4 (4.9)</td>
<td>164.8 (5.3)</td>
</tr>
<tr>
<td>Weight (kg)*</td>
<td>73.9 (6.0)</td>
<td>56.3 (7.5)</td>
</tr>
<tr>
<td>Upper Limb Length (cm)*</td>
<td>89.5 (2.9)</td>
<td>82.4 (2.0)</td>
</tr>
</tbody>
</table>

*Significant difference between males and females (p<.001)
*Abbreviations: yrs, years; cm, centimeters; kg, kilograms.

### Table 2. Performance test correlations.

<table>
<thead>
<tr>
<th>Performance Test</th>
<th>Dominant Side UQYBT</th>
<th>Non-dominant Side UQYBT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Excursion</td>
<td>Total Excursion</td>
</tr>
<tr>
<td></td>
<td>Pearson’s</td>
<td>p value</td>
</tr>
<tr>
<td>Push-Ups*</td>
<td>0.34</td>
<td>0.07</td>
</tr>
<tr>
<td>Sit-Ups</td>
<td>0.25</td>
<td>0.19</td>
</tr>
<tr>
<td>Trunk Flexor Endurance</td>
<td>0.21</td>
<td>0.26</td>
</tr>
<tr>
<td>Trunk Extensor Endurance</td>
<td>0.27</td>
<td>0.15</td>
</tr>
<tr>
<td>Dominant LTET*</td>
<td>0.35</td>
<td>0.06</td>
</tr>
<tr>
<td>Non-dominant LTET*</td>
<td>0.40</td>
<td>0.03</td>
</tr>
<tr>
<td>CKCUEST*</td>
<td>0.43</td>
<td>0.02</td>
</tr>
<tr>
<td>STRM (dominant side)</td>
<td>0.17</td>
<td>0.37</td>
</tr>
<tr>
<td>STRM (non-dominant side)</td>
<td>0.19</td>
<td>0.31</td>
</tr>
</tbody>
</table>

*Significant association observed at p < 0.05*
*Abbreviations: UQYBT, Upper Quarter Y-Balance Test; LTET, Lateral Trunk Endurance Test; CKCUEST, Closed Kinetic Chain Upper Extremity Stability Test; STRM, side-lying trunk rotation measurement.*
composite score as well as limb symmetry indices are presented in Table 3. There was no statistically significant difference between dominant and non-dominant limbs on any of the measures (p value range = 0.39-0.76); however, performance in each direction of the UQYBT was greater when the non-dominant UE was being tested as the stabilizing limb. The LSI was above 98% for the medial, inferolateral, and total excursion measurements and approximately 95% for the superolateral measurement.

A post hoc analysis comparing genders revealed that while males consistently demonstrated higher performance levels on each of the performance tests, there was no statistical difference between the genders on the CKCUEST, trunk flexor and extensor endurance tests, and the normalized UQYBT composite score (Table 4).

**DISCUSSION**

The UQYBT was found to be a reliable assessment of unilateral UE CKC excursion ability in healthy college-aged subjects, confirming the reliability reported by Gorman et al. Results also indicated there is a significant, albeit moderate relationship between performance on the UQYBT and the LTET, CKCUEST, and push-ups. This suggests that the tests are interrelated but do not necessarily assess equal components of UE CKC ability. Finally, there was no difference in UQYBT performance between dominant and non-dominant limbs. The symmetry between limbs indicates that non-injured UE performance may serve as a reasonable baseline measure when testing an injured UE, regardless of dominance.

The UQYBT is the first reliable test designed to assess unilateral UE dynamic function in a purely CKC

<table>
<thead>
<tr>
<th>Table 3. <strong>UQYBT Performance by upper extremity dominance.</strong></th>
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<tbody>
<tr>
<td><strong>Performance Test</strong></td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>UQYBT Medial Reach (cm)</td>
</tr>
<tr>
<td>UQYBT Superolateral Reach (cm)</td>
</tr>
<tr>
<td>UQYBT Inferolateral Reach (cm)</td>
</tr>
<tr>
<td>UQYBT Total Excursion (cm)</td>
</tr>
<tr>
<td>UQYBT Composite Score</td>
</tr>
</tbody>
</table>

| Abbreviations: **UQYBT, Upper Quarter Y-Balance Test; UE, Upper Extremity; LSI, Limb Symmetry Index; cm, centimeters.** |

<table>
<thead>
<tr>
<th>Table 4. <strong>Performance test values.</strong></th>
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<tbody>
<tr>
<td><strong>Performance Test</strong></td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>Push-ups §</td>
</tr>
<tr>
<td>Sit-ups*</td>
</tr>
<tr>
<td>Trunk Flexor Endurance (sec)</td>
</tr>
<tr>
<td>Trunk Extensor Endurance (sec)</td>
</tr>
<tr>
<td>Dominant LTET (sec)*</td>
</tr>
<tr>
<td>Non-dominant LTET (sec)*</td>
</tr>
<tr>
<td>CKCUEST</td>
</tr>
<tr>
<td>Dominant Side UQYBT Excursion (cm)*</td>
</tr>
<tr>
<td>Dominant Side UQYBT Composite</td>
</tr>
<tr>
<td>Non-dominant Side UQYBT Excursion (cm)*</td>
</tr>
<tr>
<td>Non-dominant Side UQYBT Composite</td>
</tr>
</tbody>
</table>

* Significant difference between males and females at p<0.05.
§ Significant difference between males and females at p<0.001.

Abbreviations: **LTET, Lateral Trunk Endurance Test; CKCUEST, Closed Kinetic Chain Upper Extremity Stability Test; UQYBT, Upper Quarter Y-Balance Test; sec, seconds; cm, centimeters.**
manner.20 While the CKCUEST has been reported to be a reliable assessment of UE performance,1 the greatest limitation with this test is the inability to account for the degree of unilateral limb difference due to injury or other factors. The UQYBT enables independent upper limb assessments, which would allow for comparisons to be made between injured and non-injured limbs. Calculating the LSI using such unilateral assessments is appealing in the clinical setting. Based on the results of this study, UQYBT performance of a non-injured limb appears to be an appropriate reference for “normal” within an individual.

One of the objectives of this research was to understand more fully what the UQYBT measures. Ultimately, the UQYBT appears to be most related to dynamic tests involving core stability (i.e., LTET) and UE CKC performance (i.e., CKCUEST and push-ups) and does not appear to be related to trunk rotation, shoulder AROM, or shoulder isometric strength. There was a statistically significant fair (dominant side) to moderate (non-dominant side) correlation between the UQYBT and the CKCUEST. These results suggest that the two tests are interrelated but measure different components or functions. Because both tests require stabilization from being in the push-up position, one would expect some relationship between the two tests. However, during the UQYBT the stance limb is held in-place and the subject moves around that limb to reach with the opposite extremity. The performance on the UQYBT in reference to the stance limb is purely CKC with a fixed external load. In contrast, the CKCUEST does not appear to solely measure CKC ability. During the CKCUEST the subject's hands are repeatedly shifted back and forth from the ground while simultaneously lifting the contralateral limb to reach a target, for a total of 15 seconds. The CKCUEST is a rapid bilateral reaching test requiring the subject to essentially perform a combined OKC and CKC task. When observing subjects who score highest on the CKCUEST (greater than 25), the task appears to assess primarily UE plyometric ability.

There is conflicting information in the literature regarding upper limb dominance as it relates to strength and task performance.25-30 Sainburg proposed the dynamic dominance hypothesis in 2002,27 suggesting that neither upper limb is dominant, but that each is specialized for different aspects of sensorimotor performance. Goble and Brown25,28 suggested most individuals use the preferred arm to perform trajectory-dependent activities and prefer the “non-dominant” arm to stabilize objects. Cortez et al30 did not find a difference between dominant and non-dominant upper extremities using an isometric testing device. Westrick et al31 did find differences between shoulder isometric tests although the differences were not consistent in all positions. Finally, Kovaleski and colleagues26 reported a 12% CKC strength difference between dominant and non-dominant upper extremities using an isokinetic CKC testing device with the dominant limb being stronger than the non-dominant limb.

In the current study, no significant differences were observed between UQYBT performance in regards to limb-dominance, yet review of the mean values revealed the non-dominant limb performed better (as the stance limb) in each of the reach directions and subsequently achieved higher total excursion and composite scores as well. Similar to the dynamic dominance hypothesis that Sainburg27 proposed, these results suggest that while neither upper limb reach distance was statistically greater than the other, the non-dominant limb may be specialized somewhat for an aspect of sensorimotor performance that includes stabilization in some fixed external load CKC tasks. The relationship between functional UE dominance in OKC tasks and potential differences from CKC tasks warrants further investigation.

Limitations associated with this study should be addressed. The study was performed using a relatively small sample size and included only healthy individuals. Because these results are representative of a young, healthy population without UE or trunk pathology, conclusions should not be extrapolated to those with injuries or in older populations. A single tester collected all data during this study, including reliability measurements; therefore no information is available regarding interrater agreement. Gorman and colleagues reported excellent interrater reliability (ICC = 1.00) in their test population.20

The authors have anecdotally noted side-to-side differences in performance on the UQYBT in patients with various UE musculoskeletal injuries as well as post-operative shoulder patients in later phases of
rehabilitation. Additional research is necessary to establish the responsiveness of the UQYBT to wrist, elbow, and shoulder pathology. Further research is also needed to determine which muscles or muscle groups are recruited during performance on the UQYBT.

CONCLUSION
The UQYBT is a reliable UE CKC test that can be used to assess unilateral UE performance in a closed chain manner. There was a significant fair to moderate association between performance on the UQYBT and the CKCUEST, LTET, and push-ups. These results suggest the tests are interrelated but do not necessarily assess equal components of UE CKC ability. Similarity in performance bilaterally indicates that reach distances on this test using a non-injured UE (whether dominant or not) may serve as a reasonable baseline measure when comparing an injured and uninjured UE. Future research is needed to determine the clinical applicability of the UQYBT.

REFERENCES


ABSTRACT

**Purpose/Background:** Researchers have previously reported on the importance of dynamic balance in assessing an individual's risk for injury during sport. However, to date there is no research on whether multiple sport participation affects dynamic balance ability. Therefore, the purpose of this study was to determine if there was a difference in dynamic balance scores in high school athletes that competed in one sport only as compared athletes who competed in multiple sports, as tested by the Lower Quarter Y Balance Test (YBT-LQ).

**Methods:** Ninety-two high school athletes who participated in one sport were matched, by age, gender and sport played, to athletes who participated in the same sport as well as additional sports. All individuals were assessed using the YBT-LQ to examine differences in composite reach score and reach direction asymmetry between single sport and multiple sport athletes. The greatest reach distance of three trials in each reach direction for right and left lower-extremities was normalized by limb length and used for analysis. A two-way ANOVA (gender x number of sports played) was used to statistically analyze the variables in the study.

**Results:** No significant interactions or main effects related to number of sports played were observed for any YBT-LQ score (p>0.05). Male athletes exhibited significantly greater normalized reach values for the posteromedial, posterolateral, and composite reach while also exhibiting a larger anterior reach difference when compared to the females. Athletes who participated in multiple sports had similar performances on the YBT-LQ when compared to athletes who participated in a single sport.

**Conclusions:** The findings of this study suggest that the number of sports played by a high school athlete does not need to be controlled for when evaluating dynamic balance with the YBT-LQ.

**Key Words:** Lower Quarter Y Balance Test; Pre-Participation testing; Multiple-sport athlete

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Disclosure Statement: Drs. Kiesel & Plisky have equity interests in Move2Perform, LLC that owns the Y Balance Test™

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INTRODUCTION
Musculoskeletal injuries are one of the potential negative side effects from exercise. The short-term consequences of musculoskeletal injuries may include reduced playing time and possible loss of an entire season of sports participation, while the long-term impact of musculoskeletal injuries may lead to chronic musculoskeletal problems that limit activity. With the growing concern over the long term consequences associated with exercise related injuries, many tools have been developed to screen athletes for increased injury risk. The goals of these tools are to identify individuals with increased susceptibility to injury so that intervention programs can be targeted for individuals with an elevated risk of injury.

The Lower Quarter Y-Balance Test™ (YBT-LQ) protocol, a validated and reliable derivation of the Star Excursion Balance Test, has been used as a mechanism to screen individuals for limitations in dynamic balance. Poor performance on the YBT-LQ has been associated with elevated risk for non-contact lower extremity injury. Other researchers have reported decreased dynamic balance in patients who have a history of chronic ankle instability or who are ACL deficient. Additionally, several researchers have reported that dynamic balance can be modified with neuromuscular training programs, suggesting that it may be possible to mitigate the elevated injury risk that was identified with the YBT-LQ.

Currently, there have been no reports that have examined dynamic balance and lower extremity proprioception differences between athletes that participate in a single sport as compared to athletes who participate in multiple sports. It would be expected that athletes that sustain and react to different perturbations through multiple sports could potentially develop varied and adaptable balance strategies. Thus, it would be expected that multiple sport athletes might exhibit improved performance on dynamic balance testing simply due to the factor of multiple sport participation. Therefore, examining the effect of multiple sport participation on balance performance is important, particularly in a high school setting where the athletes are at the greatest risk for injury and also tend to participate in more than one sport.

While there are known performance differences on the YBT-LQ across sport, gender, and competition level, there are presently no reports available on the effect of participation in multiple sports on YBT-LQ score. Therefore, the purpose of this investigation was to determine if differences exist in YBT-LQ scores between high school athletes that compete in a single sport as compared to multiple sport athletes. The effect of gender on this relationship was also examined due to the current literature supporting the construct that neuromuscular differences between genders may play a role in the increased risk of injury among female athletes.

METHODS

Subjects
The subjects recruited for the study were part of a large database of high school athletes who were tested during pre-season physicals for dynamic balance in addition to the standard physical examination. An a-priori power analysis was conducted to determine the minimum number of subjects that would be required to have adequate statistical power. Using $\alpha = 0.05$ and $\beta = 0.20$ and data from a prior study by Herrington and colleagues, it was determined that 15-22 subjects were required in each group to observe a clinically relevant differences in YBT-LQ scores. From the database, ninety-two high school athletes were identified that participated in a single sport that had an adequately matched control who participated in the same sport as well as in one or more additional sports. Subjects were matched, by age, gender (24 female pairs and 68 male pairs) and sport played. Subjects were excluded from the study if they had a lower extremity amputation, vestibular disorder, lack of medical clearance for participation, undergoing treatment for inner ear, sinus or upper respiratory infection or head cold, or cerebral concussion within the previous 3 months. All athletes were free from injury at the time of testing. Unfortunately, no information was available on history of injury for the subjects. Prior to participation all subjects read and signed informed consent forms approved by the Institutional Review Board at the author’s university at the time of data collection.

Measures

Lower Quarter Y-Balance Test (YBT-LQ)
YBT-LQ collection occurred using a previously established standardized testing protocol that has shown to...
be reliable. First, the subjects viewed a standard video demonstration followed by six practice trials prior to testing. Afterwards, all subjects performed the YBT-LQ with shoes off in an effort to decrease the possible influences footwear may have on balance. The subject began the test by standing with one foot on the stance plate with the most distal aspect of the foot at the starting line, and then was asked to reach with the opposite leg in the anterior (Figure 1, forward), posteromedial (Figure 1, back and out to the side of the reaching leg), and posterolateral directions (Figure 1, back and behind the side of the stance leg). The testing order was 3 trials standing on the right foot reaching in the anterior direction (right anterior reach) followed by 3 trials standing on the left reaching in the anterior direction. This procedure was repeated for the posteromedial and then the posterolateral reach directions. During the trials, the reach foot was not allowed to touch down on the floor or gain balance from the reach indicator or support pipe. If the subject was unable to perform the test according to the above criteria in six attempts, the subject failed that direction, no data were collected and another trial was conducted.

Reach distance was measured from the most distal aspect of the toes of the stance foot to the most distal aspect of the reach foot in the anterior, posteromedial, and posterolateral directions. The greatest reach of three trials for each direction, for each leg, was used for analysis. Reach distances were normalized to limb length, using the measured distance from the ASIS to medial malleolus in supine. A composite reach score was obtained by taking the average of the normalized reach scores [(Normalized Anterior + Normalized Posteromedial + Normalized Posterolateral)/3]. Reach symmetry was also assessed by obtaining the difference in the absolute reach distance between left and right sides for all reach directions.

Figure 1. The three reach directions of the Lower Quarter Y Balance Test (a. anterior, b. posteromedial, c. posterolateral).

Data Analysis
A two-way analysis of variance was used for analysis with gender and sport classification (one vs. multiple) being the two independent factors. The normalized reach scores for the left and right sides were averaged to examine performance for each independent reach directions as well as the composite score between the single and multiple sport athletes as well as the difference between genders. The examination of reach symmetry in all three directions allowed for the independent assessment of left and right comparison. An alpha level of \( p < 0.05 \) was used to determine statistical significance. All data were analyzed using SPSS for Windows, Version 14.0 (SPSS Inc, Chicago, IL).

RESULTS
Athletes who participated in only one sport were 6 months older on average than athletes who participated in multiple sports (\( p < 0.01 \), Table 1). No significant differences were observed for height or weight (\( p > 0.05 \)).
No significant interaction was found for gender and number of sports played, and there were no main effects for the number of sports played in regards to normalized anterior (p=0.55), posteromedial (p=0.74), posterolateral (p=0.41) or composite reach of the YBT-LQ (p=0.95) (Table 2). Reach symmetry was also compared and there were also no interactions or main effects for the number of sports played for any reach direction (anterior: p=0.20; posteromedial: p=0.56; posterolateral: p=0.23). Interestingly, there was a significant main effect for gender for the normalized posteromedial, posterolateral and composite YBT-LQ scores as well as the anterior difference (p=0.03) (Figures 2 & 3). Males exhibited greater posteromedial (p<0.01), posterolateral (p<0.03), and composite reach (p<0.03) while females exhibited a lower anterior reach difference (p<0.03).

**DISCUSSION**

The findings from this study suggest that high school athletes who participate in multiple sports do not perform differently on the YBT-LQ than comparable high school athletes who only participate in one sport only. Thus, when evaluating an athlete's performance on the YBT-LQ, the number of sports played by the athlete does not appear to be a significant factor that affects test performance. While not a primary focus of this study, it was also observed that males exhibit greater performance on the YBT-LQ in the posteromedial,

### Table 1. Characteristics single sport and multiple sport high school athlete participants.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Single Sport (n=92)</th>
<th>Multiple Sport (n=92)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>15.9 ± 1.2</td>
<td>15.4 ± 1.2</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173.2 ± 9.2</td>
<td>172.9 ± 10.2</td>
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<tr>
<td>Weight (kg)</td>
<td>73.7 ± 19.1</td>
<td>70.5 ± 14.4</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Single Sport (n=92)</th>
<th>Multiple Sport (n=92)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite Reach Score (%LL)</td>
<td>97.1 ± 8.2</td>
<td>97.1 ± 8.4</td>
<td>0.98</td>
</tr>
<tr>
<td>Anterior Reach Score (%LL)</td>
<td>75.5 ± 7.1</td>
<td>76.4 ± 7.9</td>
<td>0.33</td>
</tr>
<tr>
<td>Posteromedial Reach Score (%LL)</td>
<td>108.2 ± 10.3</td>
<td>109.1 ± 10.2</td>
<td>0.65</td>
</tr>
<tr>
<td>Posterolateral Reach Score (%LL)</td>
<td>107.4 ± 11.4</td>
<td>105.8 ± 11.1</td>
<td>0.29</td>
</tr>
<tr>
<td>Anterior Difference (cm)</td>
<td>2.8 ± 2.2</td>
<td>3.6 ± 3.8</td>
<td>0.09</td>
</tr>
<tr>
<td>Posteromedial Difference (cm)</td>
<td>4.6 ± 4.4</td>
<td>4.3 ± 3.8</td>
<td>0.63</td>
</tr>
<tr>
<td>Posterolateral Difference (cm)</td>
<td>4.3 ± 4.3</td>
<td>5.0 ± 4.2</td>
<td>0.23</td>
</tr>
</tbody>
</table>

%LL, percent leg length

**Figure 2.** Gender differences for the normalized values of the three reach directions along with the composite score of the Lower Quarter Y Balance Test. All data are presented as mean values with the error bars representing the standard deviation. (% LL – percentage of leg length, * - indicates statistical significant differences)
posterolateral and composite reach directions when compared to females even when values are normalized for leg length. Conversely, females exhibited reduced anterior reach difference which would be associated with greater reach symmetry.

Performance on the YBT-LQ has been suggested by researchers to vary depending on an individual's competition level, sport, and gender.5 Furthermore, previous researchers have also suggested that YBT-LQ performance is affected in individuals with an injury history including an ACL rupture or chronic ankle instability.7-10 These factors should be considered when evaluating an athlete's performance on the YBT-LQ with regard to identifying athletes at an elevated risk for injury as well as in establishing objectives measures for return to sport criteria. The findings of the current study indicate that the athlete's participation in multiple sports is not a factor that affects their performance on the YBT-LQ.

It was clear from our study that high school males performed better on various reach directions of the YBT-LQ in comparison to high school females. This finding is supported by one prior study21 on the Star Excursion Balance Test (SEBT) while one other study observed that females performed better than males on the Star Excursion Balance Test.22 Both of these prior studies had smaller sample sizes and were conducted using college students on the standardized21 and abbreviated22 Star Excursion Balance test protocol. As a result there are a number of factors (such as differences in age of the subjects, testing protocol, effect of fatigue) that may have led to the differences in the findings; however, no consistent factors exist of which the authors are aware. However, it does appear that inherent gender differences do exist on the YBT-LQ and SEBT which makes it appropriate to continue to develop normative data that is gender specific. The development of gender specific normative values would be helpful from a rehabilitation standpoint as clinicians aim to use performance data to make decisions regarding the readiness of patients for activity, with minimal risk of re-injury.17

Several limitations of the current study should be noted. The primary limitation of the study is that there were a disproportionate number of female and male subjects. However, it should be noted that the variability in the male and female scores on the YBT-LQ was similar across the examined for the analyzed measurements. This observation would suggest that any Type II error that may be attributed to lower subject numbers and high levels of variability would be minimal due to the relatively normalized variance between the genders. A second limitation is a lack of injury history on the subjects included in the study. Prior research has suggested that patients with ACL injury or chronic ankle instability perform lower on the SEBT.7-10 Although these limitations exist, they are not considered to be critical factors that limit the external validity of the study.

**Recommendations for Future Research**

Current evidence suggests that the YBT-LQ may be a field ready and time-expedient test that can be used to assess lower extremity injury risk in athletes. At the interscholastic level, the diagnostic ability of the YBT-LQ for identifying athletes at an elevated risk for injury has only been examined in basketball, and thus future research should assess the YBT-LQ in different sport high school populations. In addition, as the YBT-LQ grows in its use in youth populations it would be beneficial to understand how performance on the YBT-LQ is affected by maturation and growth. It may be that performance on dynamic balance can highlight when adolescents who are rapidly going through maturation may be at a greater risk for injury due to a lack of dynamic balance and proprioception. Finally,
future studies should examine whether the relationships observed in the current study are maintained in different age groups and competition levels.

CONCLUSION
The findings of this study indicate that there is no difference in the YBT-LQ performance in athletes who compete in one sport compared to athletes who compete in multiple sports. In addition, males exhibit increased performance on the YBT-LQ compared to females even when values are normalized to leg length.

REFERENCES
ABSTRACT

Background: Chronic inversion ankle sprains are common in basketball players. The effect of taping on functional performance is disputed in the literature. Kinesiotaping® (KT®) is a new method that is being used as both a therapeutic and performance enhancement tool. To date, it appears that no study has investigated the effect of ankle KT® on functional performance.

Purpose: To investigate the effects of different types of taping (KT® using Kinesio Tex®, athletic taping) on functional performance in athletes with chronic inversion sprains of the ankle.

Study Design: Crossover Study Design

Methods: Fifteen male basketball players with chronic inversion ankle sprains between the ages of 18 and 22 participated in this study. Functional performance tests (Hopping test by Amanda et al, Single Limb Hurdle Test, Standing Heel Rise test, Vertical Jump Test, The Star Excursion Balance Test [SEBT] and Kinesthetic Ability Trainer [KAT] Test) were used to quantify agility, endurance, balance, and coordination. These tests were conducted four times at one week intervals using varied conditions: placebo tape, without tape, standard athletic tape, and KT®. One-way ANOVA tests were used to examine difference in measurements between conditions. Bonferroni correction was applied to correct for repeated testing.

Results: There were no significant differences among the results obtained using the four conditions for SEBT (anterior p = 0.0699; anteromedial p = 0.126; medial p = 0.550; posteromedial p = 0.587; posterior p = 0.754; posterolateral p = 0.907; lateral p = 0.124; anterolateral p = 0.963) and the KAT dynamic measurement (p = 0.388). Faster performance times were measured with KT® and athletic tape in single limb hurdle test when compared to placebo and non-taped conditions (Athletic taping- placebo taping: p = 0.03; athletic taping- non tape p = 0.016; KT®- Placebo taping p = 0.042; KT®-Non tape p = 0.016). In standing heel rise test and vertical jump test, athletic taping led to decreased performance. (Standing heel rise test: Athletic taping- placebo taping p = 0.035; athletic taping- non tape p = 0.043; KT®- KT® p = 0.001) (Vertical jump test: Athletic taping- placebo taping p = 0.002; athletic taping- non tape p = 0.002; KT®- athletic tape p = 0.001)

Conclusion: Kinesiotaping® had no negative effects on a battery of functional performance tests and improvements were seen in some functional performance tests.

Clinical Relevance: Ankle taping using Kinesio Tex® Tape did not inhibit functional performance.

Key Words: Chronic inversion ankle sprain, functional performance tests, Kinesiotaping
INTRODUCTION

The ankle is the most commonly injured joint in court games and team sports, such as rugby, soccer, volleyball, handball, and basketball. In a large-scale systematic review which considered articles published from 1977 to 2005, Tik-Pui Fong et al demonstrated that in indoor volleyball, American football, martial arts, basketball, aeroball, ultimate Frisbee, flag football, cheerleading, indoor soccer, ice hockey, lacrosse, badminton and netball more than 80% of ankle injuries were ankle sprains.1

Ankle injuries can be defined as either acute or chronic, with ligamentous injury the most common acute diagnosis. About 85% of all ankle injuries are ankle sprains involving the lateral ankle ligaments. Chronic injuries are often related to, or are the sequellae of acute sprains, or overuse syndromes of the surrounding soft tissues. Intuitively, ankle sprains are most common in contact sports, indoor sports, and sports with high frequency of jumping.2

Functional ankle instability (FAI) is seen in about 40% of all patients that sustain an ankle sprain3,4 and is defined as a “disabling loss of reliable static and dynamic support of a joint” and a “tendency for the foot to give way”.5, p.3 Researchers have hypothesized that people with FAI have functional performance deficits.6-8 Functional performance tests are used to measure joint stability muscle flexibility, muscle strength and power, proprioception, dynamic balance, and agility.5

Many athletes from different sports think that taping and bracing is important in acute and chronic phases of an ankle injury. Certainly, many athletes believe that ankle support is important for their performance.9 Ankle injuries are quite common in the sport of basketball, and they are among the most severe as defined by time loss during the season.10-12 A study of Australian basketball players showed that ankle injuries were responsible for over half (53.7%) of total time absent from basketball in a season.13

Functional performance effects of ankle taping and bracing have been assessed in both injured and uninjured subjects.14,17 However, no consensus exists regarding whether ankle supports of various brace designs (e.g. semi-rigid versus lace-up) interfere with normal function or not. According to some investigators, vertical jump was decreased in athletes using various forms of ankle support by 3% to 5%,14,18-21 while no significant effect was found by others.16,17,22-28 A significant decrease in performance on multidirectional agility tests for uninjured subjects wearing ankle support was observed by some researchers14,18 whereas other researchers demonstrated no difference between supported and unsupported conditions.21,22,24,26-29

Kinesiotaping® (KT®) method is a relatively new taping technique which requires Kinesio Tex® tape. Tape used for KT® is different from taping using traditional white athletic tape. First, it has elasticity in one direction and before applying to skin it can be stretched to 140% of its original length.30 It provides a constant pulling (shear) force to the skin. Second, Kinesio Tex® tape is air permeable and water resistant and can be worn for several days without removal. KT® is being used following injury and during the rehabilitation.30,32 Athletic tape is structurally supportive whereas Kinesio Tex® tape may have therapeutic benefits.30 Kenzo Kase, the creator of Kinesio Tex® tape, proposed the following mechanisms for the effects of Kinesio Tex® Tape: 1. Altered muscle function by the tapes effects on weakened muscles, 2. Improved circulation of blood and lymph by eliminating tissue fluid or bleeding beneath the skin, 3. Decreased pain through neurological suppression, and 4. Repositioning of subluxed joints by relieving abnormal muscle tension, and helping to affect the function of fascia and muscle.31 Murray has suggested a fifth mechanism, which is increased proprioception through increased stimulation to cutaneous mechanoreceptors.32

The purpose of this study was to investigate the effects of different types of taping (KT® using Kinesio Tex®, athletic taping) on functional performance in athletes with chronic inversion sprains of the ankle.

METHOD

Participants: Twenty male basketball players volunteered to participate in this study. Fifteen players between the ages of 18 and 22 (mean age: 20.33 ± 1.4 yrs) were eligible to participate in the study. Demographic characteristics of the participants are shown in Table 1. Ethical approval from the Ethics Commit-
The inclusion criteria was having sustained recurrent ankle inversion sprains (at least three sprains) and having the diagnosis of FAI according to the Cumberland Ankle Instability Tool (CAIT) while the exclusion criteria were: 1) history of ankle fracture, 2) ankle injury within three months of participation, 3) history of anterior cruciate ligament injury, 4) current participation in supervised physical rehabilitation, 5) any neurological deficit.

Three of the players were excluded from the study because they were found to have knee pain during the tests. Another two players were excluded due to ankle pain during post-training evaluation.

**Test Procedures:** Functional ankle instabilities of subjects were classified according to the Cumberland Ankle Instability Tool (CAIT). The participants were unaware of which criteria shows functional ankle instability. CAIT is comprised of 9 adjectival scale questions. The CAIT has a high inter-rater reliability – ICC[2,1]: 0.96. Upon completing the questionnaire a score between 0 and 30 is obtained. According to CAIT recommendations, scores ≥ 28 indicate stability while scores ≤ 27 indicate FAI.

The performance tests mentioned below were performed by all subjects in four different conditions: with placebo taping, without any taping, with athletic taping, and with KT® at one-week intervals. Subjects performed a 20 minutes warm-up before testing. They did their own warm-up exercises; running, stretching and shooting which were a routine part of team warm up.

**Hopping Test:** The hopping test as described by Amanda et al assesses single limb agility and motor control on uneven surfaces. The course consists of leveled squares and 4 squares with a 15° incline in different directions. Subjects were ordered to hop around the squares and finish the test as fast and accurately as possible. Each time they stepped outside a square or used the uninvolved foot, one second was added to the final time (Fig. 1). Trial reliability of the single-limb hopping test was high: intra-class correlation coefficient ICC[2,1]:0.93. Standard error: 0.18 second.

**Single Limb Hurdle Test:** The single-limb hurdle test involves 10 squares on the floor and three hurdles, which are about 15 cm high, connected to athletic tape placed as seen in Fig. 2. Each subject performed 2 lateral jumps and 1 medial jump. Participants were asked to hop through the courses as quickly as possible and their times were recorded. If the participant touched the athletic tape or cone while completing the course, touched the contralateral foot down, or hopped out of sequence the participant was asked to start over. Trial reliability of the single-limb hurdle test was high ICC[2,1]: 0.90, Standard error 0.26 second.
Vertical Jump Test: For the vertical jump test, the participants stood with their side to the wall, feet flat on the ground. They extended their arm as high as possible, and the point was marked on the wall. The athlete was then cued to jump as high as possible projecting their body upwards and the highest point they touched was marked. (Note: they were allowed to use the countermovement of the arms.) The participants’ test foot (taped foot side/one lower extremity) jump was assessed. The best value of the three trials was recorded in centimeters.35,36

Standing Heel Rise Test: The isotonic endurance of the ankle joint plantar flexor muscles was measured by this test based on the methodology described by Ross and Fontenot.37 The test-retest reliability of the standing heel-rise test has been shown to be excellent in healthy populations (ICCs range = 0.78-0.96).38 Subjects were allowed to touch their fingers to the wall at shoulder level to help them keep their balance. Heel-rises were then performed at a rate of one heel-rise at 40 beats per minute, performed to the beat of a metronome. Heel rises above 5 cm were counted. The testing leg had to be kept straight. The test ended when the subject was unable to do proper

Figure 1. A: Hopping course; B: Subject performing hopping course.

Figure 2. Single Limb Hurdle Test.
heel-raises due to fatigue. This test involved one trial (Fig. 3).

**The Star Excursion Balance Test (SEBT):** The Star Excursion Balance Test (SEBT) provides accurate data in the measurement of athletes’ postural control. The aim of SEBT is to reach the furthest possible point with one leg while maintaining balance on the contralateral leg. Subjects stand with the involved limb placed at the center of a grid, which has 8 lines extending at 45° increments (Fig. 4). Those lines are named according to the excursion direction related to the stance leg: Anterior (A), Anterolateral (AL), Anteromedial (AM), Posteromedial (PM), Posterior (P), Posterolateral (PL), Medial (M) and Lateral (L). Subjects are allowed to extend on one leg 4 times in 8 directions. Therefore, subjects were familiarized to the test as recommended by Hertel et al. During the test, the subjects kept their taped leg planted firmly on a mark and extended the other leg as far they could while maintaining balance on each vector and each distance was recorded. To ensure the achievement of stability via neuromuscular control of the stance leg, the subjects were told to touch the ground lightly with the reach foot. Three reaches were performed in each direction and their mean was recorded. There was a 30 second break between each reach. The distance of each reach was divided into the leg length of the subject and multiplied by 100 to keep the subject’s leg length from affecting the results and to obtain results in the form of a percentage. The starting position, although the subjects always turned clockwise, was randomized to eliminate learning effect. The test was repeated if the subjects made the following mistakes: 1) Subject’s foot did not make contact with the ground while standing on the stance leg. 2) Moving the stance foot. 3) Losing balance at any time in the trial. 4) Failing to maintain start and return positions for one full second.

**SportKAT (Kinesthetic Ability Trainer):** The Kinesthetic Ability Trainer (KAT) 3000 (Breg, Vista, CA) was
used to measure kinesthesia. The KAT 3000 is made of a platform, which is moveable but supported on a central point by a small pivot. There is a connection to computer via a tilt sensor on the platform which records the deviation of the platform from a reference position 18.2 times each second (Fig. 5). Each recording measure was the distance between the central point and the reference position. Then, a balance index is calculated through the summation of these distances. A low balance index shows success in performance of the test. Subjects were asked to maintain a unilateral stance on the test leg. The trial included two different tasks, one static and one dynamic. In the static balance task, athletes were asked to stand on one leg (tested leg) and keep the center point that was represented by a cross on the computer screen. In the dynamic balance task, athletes made the cross (center point) follow the cursor (reference position) on the computer screen. Both static and dynamic balance tests consisted of three measurements, which each lasted at 30 seconds. During all the tests the athlete crossed their arms over their chest and looked at the computer screen. Before each task, the athlete was allowed to practice for 1 min and the break between the static and dynamic test tasks was 15 minutes. If an athlete was unable to keep his balance during a measurement and touched the railing, the measurement was cancelled and restarted.

**Taping Methods**

**Kinesiotaping** method: The applied tape involved both tibiofibular ligament and peroneal muscle support techniques using Kinesio Tex® Tape by same physical therapist who is trained in applying KT® (Fig. 6). While applying the peroneus longus muscle support tape application, the athlete’s position was supine or long sitting. The base of the Kinesio Tex® Tape was applied to the plantar surface of the base of the 1st metatarsal. The ankle was plantar flexed and inverted to increase tissue tension while Kinesio Tex® Tape was applied over the path of the peroneus longus tendon, passing behind the lateral malleolus and ending on the fibular head. The taping method for peroneus brevis muscle differs from that of the peroneus longus; the ankle is dorsiflexed and inverted to increase tissue tension. The rest of the tape was applied along the path of the peroneus muscles and attached to fibular head.

![Figure 5. The SportKAT 3000 device.](image1)

![Figure 6. Kinesiotaping application for ankle (note peroneus longus in pink colored tape, peroneus brevis in black colored tape, and anterior tibiofibular ligament in flesh colored tape).](image2)
For the tibiofibular ligament support technique with Kinesio Tex® Tape, athletes extended their knee and dorsiflexed their ankle. Then, Kinesio Tex® Tape was applied to medial malleolus. After stabilizing the tape, it was pulled with light (25%) tension towards to lateral malleolus (through anterior part of ankle) by covering the anterior and posterior tibiofibular ligaments and the end of the technique Kinesio Tex® Tape was attached with no tension.

In the athletic taping method first pre-wrap was applied. Two strips of white 2 inch athletic tape were used separately as anchors at the top of the pre-wrap around the calf. Two medial to lateral stirrups and horizontal stirrups were used to support both sides of the ankle. Finally, medial and lateral heel locks as well as figure of eight straps were applied (Fig. 7).

Athletic tape was used for the placebo taping method. ‘I’ shaped tapes were cut and applied with no tension (Fig. 8).

Statistical analysis
SPSS Version 19 software was used. Statistical analyses performed consisted of one way ANOVA tests to examine difference in measurements between conditions. Bonferroni correction was applied to correct for use of multiple tests.
RESULTS
The means and standard deviation scores on each of the functional performance tests are presented in Table 2. The mean performance time for the hopping test was fastest in the athletic tape condition (6.56 seconds) followed by the KT® condition (6.62 seconds) as compared to placebo tape (7.01 seconds) and non-taped condition (7.21 seconds). The only statistically significant difference was found between the athletic tape and non-taped conditions (p=0.035).

In the single limb hurdle test fastest performance was measured in KT® condition (5.17 seconds) then in athletic taping condition (5.26 seconds), followed by placebo tape (5.41 seconds) and non-taped condition (5.50 seconds). These differences were statistically significant when compared among conditions (Athletic taping- placebo taping p=0.03; athletic taping- non tape p=0.016; KT®- athletic taping p=0.042; KT®- Non tape p=0.016).

In both the standing heel rise test and vertical jump test, athletic taping led to diminished results. The mean number of heel rises performed was in the athletic tape condition (25.7). While in vertical jump test results greatest height was measured in KT® condition (33.4 cm) followed by non tape (32.9 cm), placebo tape (32.7 cm) and then athletic taped condition (29.9 cm).

In both the heel rise and vertical jump tests the performance decreases observed with the athletic tape condition were statistically significantly different than other conditions.

The following summarizes the statistical analysis (p values) during the standing heel rise test and vertical jump test. Athletic taping- placebo taping p=0.035; athletic taping- non tape p=0.043; KT®- athletic taping p<0.001. For vertical jump test: Athletic taping- placebo taping p=0.002; athletic taping- non tape p=0.002; KT®-athletic taping p<0.001. (Figure 9,10) Finally, there was no significant difference between the performance of the athletes with placebo taping and those without taping in any of the functional performance tests.

Star excursion balance test (SEBT) scores are shown in Table 3. No significant differences were observed among all the trials of the SEBT (anterior p=0.069;
anteromedial \( p = 0.126 \); medial \( p = 0.550 \); posteromedial \( p = 0.587 \); posterior \( p = 0.754 \); posterolateral \( p = 0.907 \); lateral \( p = 0.124 \); anterolateral \( p = 0.963 \) and KAT Dynamic tests \( p = 0.388 \).

**DISCUSSION**

The results of the current study showed that KT\(^8\) did not cause any decrease in performance on any of the functional tests performed by athletes with chronic inversion ankle sprains. This is in agreement with other studies that reported similar conclusions as a result of the utilization of external ankle supports.\(^{7,16,34}\) There were no significant differences in performance by athletes with placebo taping and without taping conditions on any of the functional performance tests. Similarly, Sawkins et al.\(^{44}\) found no significant effects of placebo taping in their study. However, in the study conducted by Sawkins et al.,\(^{44}\) participants reported improved perceptions of stability, confidence, and reassurance with the placebo tape in place while performing functional tests.

The SportKAT 3000 is a fully computerized dynamic platform with forward-backward and side-to-side tilting that evaluates subjects' reactions to different types of surface displacement. It is designed for static and dynamic balance assessment and training. In the current study, there were no significant differences among all taping conditions for dynamic balance measurement. In static balance assessments, subjects who had Kinesio\(^\text{Tex}\)\(^\text{®}\) Tape applied demonstrated statistically significant lower balance index scores (the lower balance score, the better success) than those who wore either placebo taping or no tape. However, it was stated that there was no change in performance in either static or dynamic balance function regardless of the taping technique used in studies by Greene&Hilman,\(^{45}\) Hume&Gerrard,\(^{46}\) and Hopper et al.\(^{47}\) In these studies, balance ability was measured by taking stabilometric recordings in single leg stance position.\(^{45-47}\)

Cordova et al\(^{48}\) stated that “lace-up style ankle support and traditional adhesive tape application incorporate material anterior and posterior to the talocrural joint axis.”\(^{48}\), p.640 This may restrict plantar flexion ROM that could contribute to a diminished vertical jump height. Vertical jump height could become impaired if the external ankle support decreases functional ROM.\(^{48}\) Subjects in the current study who were taped with athletic tape demonstrated vertical jump heights that were significantly lower than subjects with other conditions, perhaps due to the restriction of plantar flexion as described above. Mayhew\(^{20}\) examined the effects of closed basketweave taping application on the vertical jump, 50-yd sprint, standing long jump, and the Illinois agility run. He reported that the taping application significantly impaired vertical and long jump ability and concluded that the taping application significantly reduced performance when plantar flexion of the ankle was required. In the current study; despite of the statistically significant negative

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**Figure 9.** Means plot of standing heel rise test results. ENDN = non-taped condition, ENDK = Kinesiotaped condition, ENDA = athletic tape condition, ENDP = placebo condition.

**Figure 10.** Means plot of vertical jump test measurement. VJN = non-taped condition, VJK = Kinesiotaped condition, VJA = athletic tape condition, VJP = placebo condition.
effects of athletic taping on vertical jumping, KT did not produce any statistically significant negative effects.

The hopping test and the single limb hurdle test are useful functional performance tests because they require multiple demands such as muscular strength, neuromuscular coordination, and joint stability. In this study the authors found no significant difference between outcomes in the hopping or single limb hurdle tests in athletes with athletic tape and KT®, both of them were to be found no different than the performance of athletes with placebo taping. The current findings are in agreement with Sawkins et al. who found no significant difference (p= 0.865) by comparing performance on the hopping test in those with placebo taping compared to non-taped controls. SEBT was used as a dynamic postural control measurement. SEBT was chosen because it is a reliable test that assesses dynamic stability in multiple planes. Hardy et al. used a prophylactic ankle brace as an external ankle support and they found that the bracing condition had no effect on any of the SEBT directional measures. The findings of the current investigation findings are in agreement with Hardy et al, as there was no significant difference in performance on the SEBT among athletes with all tape conditions.

The standing heel rise test was used to examine the isotonic endurance of the ankle joint plantar flexor muscles. However Madeley et al. suggested that although this test principally measures function of the gastrocnemius and soleus muscles, the input of other muscles of the leg on the plantar flexion of ankle joint cannot be ignored.

The authors of the current study found that athletic tape significantly reduced the number of heel raises performed (Non tape- athletic taping p= 0.043; placebo taping- athletic taping: p 0.035; KT®- athletic tape p< 0.001). The cause of this decrease could be because the limitation of plantar flexion ROM of ankle. Performance in the Kinesio Tex Tape® showed higher numbers of heel rises than athletic tape condition. There were no statistically significant differences in heel rises between KT®-none-tape and KT®-placebo. The reason for this may be the proprioceptive feedback, which was also investigated by Sawkins et al., and the effect of placebo taping remains unclear.

<table>
<thead>
<tr>
<th>Tests</th>
<th>Placebo Taping</th>
<th>Without taping</th>
<th>Athletic Taping</th>
<th>Kinesio Taping</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEBT Anterior (cm)</td>
<td>82.42 ± 4.21</td>
<td>82.32 ± 4.21</td>
<td>82.82 ± 4.04</td>
<td>82.74 ± 4.49</td>
</tr>
<tr>
<td>SEBT Anteromedial (cm)</td>
<td>75.21 ± 3.43</td>
<td>76.72 ± 2.85</td>
<td>76.88 ± 3.62</td>
<td>76.80 ± 3.16</td>
</tr>
<tr>
<td>SEBT Medial (cm)</td>
<td>85.02 ± 8.29</td>
<td>85.10 ± 9.57</td>
<td>84.52 ± 8.62</td>
<td>85.05 ± 8.82</td>
</tr>
<tr>
<td>SEBT Posteromedial (cm)</td>
<td>85.54 ± 7.18</td>
<td>85.01 ± 8.16</td>
<td>85.09 ± 7.61</td>
<td>85.49 ± 7.49</td>
</tr>
<tr>
<td>SEBT Posterior (cm)</td>
<td>92.52 ± 5.71</td>
<td>92.73 ± 6.90</td>
<td>92.41 ± 6.11</td>
<td>92.80 ± 6.27</td>
</tr>
<tr>
<td>SEBT Posterolateral (cm)</td>
<td>82.14 ± 6.97</td>
<td>81.87 ± 6.90</td>
<td>81.87 ± 6.73</td>
<td>81.94 ± 6.82</td>
</tr>
<tr>
<td>SEBT Lateral (cm)</td>
<td>68.48 ± 6.21</td>
<td>68.41 ± 6.44</td>
<td>69.48 ± 6.61</td>
<td>68.75 ± 5.58</td>
</tr>
<tr>
<td>SEBT Anterolateral (cm)</td>
<td>79.33 ± 5.79</td>
<td>79.46 ± 6.28</td>
<td>79.42 ± 5.96</td>
<td>79.52 ± 5.48</td>
</tr>
</tbody>
</table>

Table 3. Star excursion balance test scores (cm).
Another discussion point is the duration of the effectiveness of tape for support of the ankle. Athletes would prefer that taping should maintain its effectiveness during training or competition. Larsen54 recorded that there was a 20% loss of support capabilities after 20 minutes start/stop running on uneven ground and jumping. Frankney et al55 found reduction of about 50% after 15 minutes of standard vigorous exercises including jumping, pivoting, and running.55 Thus, the authors of the current study applied all taping methods 20 minutes before trials. It should be noted that a proposed advantage of KT® is that can be worn for 3 days, without diminishing effect. Besides, athletes can take a shower without taking the tape off since it is waterproof. 31 However, this claim was made related to the claim of ongoing tactile input that may be generated by KT®.

Limitations of the present study include the small sample size (n=15) and that they were a convenience sample. As the sample included only male basketball players, the application of the present findings to other populations such as female athletes and those who participate in other sports is limited.

CONCLUSION
Neither KT® nor athletic tape had a statistically significant effect on performance on the hopping test, the single limb hurdle, dynamic balance, and SEBT tests. However, athletic taping caused a significant decrease in performance in vertical jump and standing heel rise tests while KT® did not limit functional performance. This study offers information that may stimulate new design of ankle taping methods by using different materials and further research may help to reduce uncertainty of the effects of various types of ankle taping on functional performance.

REFERENCES
Subjects with Unilateral Chronic Ankle Instability. "


CASE REPORT
DIAGNOSIS OF AN ISOLATED POSTERIOR MALLEOLAR FRACTURE IN A YOUNG FEMALE MILITARY CADET: A RESIDENT CASE REPORT
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J. Parry Gerber, PT, PhD, SCS, ATC

ABSTRACT
Background and Purpose: The ankle is the most commonly injured joint during athletic activity. While ankle sprains are certainly the most common injury, ankle fractures can occur frequently. One type of ankle fracture with a reportedly low incidence is the isolated posterior malleolar fracture. Because of the low incidence, isolated posterior malleolar fractures can present a diagnostic challenge. The purpose of this case report is to describe the diagnostic process used for this rare injury that occurred in a physically active college-aged female who injured her ankle when landing from a fall during performance on a military obstacle course.

Case Description: A 19 year old female United States Military Academy cadet presented to a direct access physical therapy clinic. She was limping, not using any assistive device, and was wearing an ace bandage around her right ankle/foot. Two days earlier she fell from a “10 foot high” structure while performing the military obstacle course. She did not recall details of impact, but she was told by several bystanders that it appeared that she landed on her right foot followed immediately by a transition to her buttocks and then to her back.

Outcomes: Ottawa Ankle Rules and ligamentous testing were negative; however, she was tender to palpation just anterior to the achilles tendon and lateral to the posterior edge of the medial malleolus. Based on mechanism of injury and tenderness of the posterior ankle, a potential posterior ankle fracture was suspected and subsequently confirmed by radiographic studies of the ankle including standard radiographs and computerized tomography.

Discussion: While the Ottawa Ankle Rules are generally effective in detecting many types of ankle fractures, clinicians should not rely solely on such prediction rules. This case highlights the importance of completing a thorough history and performing a thorough physical examination. This case report focuses on differential diagnosis. It is important to consider all aspects of the patient evaluation process collectively instead of examination pieces individually.

Key words: Direct access, Ottawa Ankle Rules, posterior malleolus fracture

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*The patient gave consent for the purposes of this case report

At the time of the research, Dr Miller was completing a post-professional sports medicine physical therapy residency under the mentorship of Dr Gerber, as well as completing his DScPT in Physical Therapy from Baylor University, Waco TX. The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of Baylor University, the US Military, the Department of Defense, or the United States Government.

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INTRODUCTION

United States Military Cadets are a unique group of college-aged individuals who are required to perform high level athletic and physical activities on a regular basis. These activities often result in similar injuries as those sustained by high school and college athletes. Among these athletes, the ankle is the most commonly reported site of injury each year.1,2 Depending on the activity, a large amount of force can be imparted across the ankle joint, leading to fracture and/or ligament disruption.3,4 While sprains are certainly the most common injury to the ankle, ankle fractures are frequently seen in emergency rooms with an incidence of 1-2 per 1000 persons per year.5 With the increase of direct access in many health care facilities, it is paramount that clinicians recognize the need to obtain necessary radiographic images either via radiographic request or appropriate physician referral to correctly diagnose potential fractures of the ankle and ultimately provide proper care.

The Ottawa Ankle Rules (OAR) were developed to decrease cost of ordering extraneous radiographs while reducing the risk of missing fractures of the ankle or foot.6,7 The rules apply to any individual presenting to the emergency room or for medical care after a traumatic activity with tenderness to palpation of the posterior edge or tip of either malleoli (palpat ing 6 cm proximally) and/or inability to fully weight bear at least 4 steps.6,7 A modification called the Buffalo Ankle Rules found that tenderness to palpation of the mid body of the malleoli (palpating 6 cm proximally) was slightly more specific and equally sensitive.8 The OAR have demonstrated sensitivities of 95-100% for detecting medial and lateral malleolar fractures.6,7 Despite the success in facilitating the diagnosis of ankle fractures, the OAR have demonstrated mixed abilities with regard to ruling out certain ankle fractures such as isolated posterior malleolar fractures.6,7,9 Stiell et al7 found that in 17% of the cases in which the rules were interpreted as negative, the patients were diagnosed with a posterior malleolar fracture; however, less than 1% of the total injuries were diagnosed as posterior malleolar fractures.

Isolated posterior malleolar fractures can occur with high level activity but are rare entities. Lash et al10 found that only 4% of patients with confirmed ankle fractures over a year period had isolated posterior malleolar fractures. Neumaier et al10 performed a retrospective study of 2500 ankle lesions and found that only 25 were isolated posterior malleolar fractures. Posterior malleolar fractures usually occur in association with proximal fibular fractures (Maisonneuve), syndesmosis injuries, posterior tibiofibular ligament injury, and/or spiral tibial diaphyseal fractures. The posterior malleolus is defined as the posterior portion of the inferior articulating surface of the tibia. Volkman's triangle and the posterior tibial plafond are other terms used to describe the posterior malleolus. Lauge-Hansen devised a classification system for ankle injuries based on foot position and the force applied during the injury.11 A pronation-abduction injury was suggested as a mechanism for isolated posterior malleolar fractures.11 However, in an attempt to validate this classification system biomechanically utilizing cadaveric ankles, Michelson et al12 did not detect any posterior malleolar fractures after dissection of the cadaver specimen. The characteristic self-reported mechanism of injury for an isolated posterior malleolar fracture is hyper-plantar flexion with an axial load such as may occur with slipping and falling.6,7,10,13 Because of the low incidence, isolated posterior malleolar fractures can present a diagnostic challenge. The purpose of this case report is to describe the diagnostic process used for this rare injury that occurred in a physically active college-aged female who injured her ankle when landing from a fall during performance on a military obstacle course.

CASE DESCRIPTION

History/Subjective

A 19 year old female United States Military Academy cadet presented to a direct access physical therapy clinic wearing an ace bandage around her right ankle/foot and ambulating with a slightly antalgic weight-bearing gait without an assistive device. The cadet was participating in military field training located in a remote area. A physical therapist was present who provided musculoskeletal evaluations and applicable care for 2-3 hours daily to augment the remote primary medical care services. The subject’s verbal pain rating was 0/10 at rest, 1-2/10 with ambulation on a level surface, and 5/10 with ambulation going downhill. She stated that two days earlier she fell from a “10 foot high” structure during...
performance on the military obstacle course. She did not recall what happened to her ankle at impact, but she was told by several bystanders that it appeared that she landed on her right foot followed immediately by landing on her buttocks and then her back. Onsite medical management included ice and an ace wrap for a sprained ankle. The patient was told that she could gradually increase activity as tolerated but to follow up if she did not notice remarkable improvement after a couple of days. While the ankle did improve gradually over the next two days, she was still having pain (mostly posterior and posterolateral) with ambulation especially when walking down hills, pivoting, and weight bearing on her right lower extremity. Past medical history revealed one previous right ankle sprain one year prior to this injury, which completely resolved. The subject was taking Ibuprofen 200 mg three times a day which seemed to decrease her pain. She denied numbness and tingling, significant night pain, weight change, feeling ill, or “giving way” of the ankle.

Physical Examination
The patient entered the clinic displaying a minimal to moderate antalgic gait with a lack of push off from midstance although she was able to plantar flex slightly at terminal stance. Visual inspection of the right ankle and foot revealed moderate edema and significant ecchymosis of the lateral and posterolateral leg/ankle (Figure 1). There was no tenderness or reported discomfort at the distal lateral and medial malleoli, despite palpable edema. There was no tenderness at the proximal fibula, base of the fifth metatarsal, navicular, or calcaneus. Active range of motion and passive range of motion was full with pain reported as 3 out of 10 at end range plantar flexion. Special tests including the fibular syndesmosis squeeze, external rotation test, and anterior drawer tests were negative with slight discomfort of the anterolateral ankle during each test, as reported by the subject. Ankle manual muscle testing was normal except for 4/5 with resisted plantar flexion with pain reported posteriorly. Because of the findings of the physical examination and the posterior ankle complaints when walking down hill, further palpation was performed which revealed tenderness just anterior to the Achilles tendon and lateral to the posterior edge of the medial malleolus that reproduced her symptoms.

Differential Diagnosis
Differential diagnoses considered at that time included posterior malleolar fracture, lateral malleolar avulsion fracture, or severe ankle sprain. Initially there was a low suspicion of fracture, because the typical application of Ottawa Ankle Rules were negative, as the patient could ambulate with low to moderate pain, no tenderness to palpation at the malleoli, and overall she was improving. Additionally, ligamentous testing was negative and pain free. Given the extent of edema and ecchymosis, a fall from a height approximately 10 feet, pain located posteriorly, and a possible forced ankle plantar flexion with axial load mechanism a posterior
malleolar fracture became the leading suspected diagnosis. A concomitant Maisonneuve fracture was not suspected, because the patient was not tender at the proximal fibula and she did not report pain or crepitus with the fibular squeeze test.

In the military, physical therapists work closely with physicians and have the opportunity to be trained and credentialed with clinical privileges to order certain radiographic studies. The therapist in this case, having imaging privileges, ordered a three view (A/P, lateral and oblique views) ankle radiograph series for the right ankle due to the suspicion of posterior malleolar fracture. The patient was issued crutches and trained in non-weight bearing ambulation.

**Outcome**
Radiographs confirmed the presence of an isolated posterior malleolar fracture (Figure 2). An orthopedic surgeon was immediately consulted for further evaluation and treatment of a posterior tibial fracture. The surgeon ordered a Computed Tomography (CT), which confirmed a non-displaced isolated posterior malleolar fracture (Figure 3). The CT scan has been advocated as the modality of choice for assessment of stability and extent of posterior malleolar fractures.14-16 The patient was placed in a non-weight bearing short leg cast with use of bilateral axillary crutches for 6 weeks. Healing of the fracture was noted on radiographs taken 6 weeks later and at that time the patient was placed in a walking boot for 2 additional weeks.

Stationary biking, range of motion exercises, and theraband strengthening exercises were initiated once the cast was removed. Swimming, a variety of balance exercises, and gait training were added when the walking boot was removed. A walk to jog program was added within 2 weeks of boot removal and by 12 weeks the

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**Figure 2.** Radiographs of the subject’s right ankle. Note the isolated, non-displaced fracture of the posterior malleolus on the lateral view (far right).

**Figure 3.** Computerized Tomographic evaluation of the lower leg. Note the isolated, non-displaced fracture of the posterior malleolus. *Left image = Sagittal view, Right image = Axial view.*
patient was running without difficulty. At that time, her ankle range of motion and strength were normal, balance appeared equal bilaterally, and hopping was painless and symmetrical when compared to the uninjured side. The patient was instructed to gradually increase all activity as tolerated and to follow-up as needed. The patient reported in an email follow-up 2 months later (20 weeks after initial evaluation) that she was completely back to full activity without limitations.

DISCUSSION

Diagnosing posterior malleolar fractures is typically more challenging than diagnosing other ankle fractures. Ankle fractures from trauma usually include the lateral malleolus, medial malleolus or a combination. The hallmark palpations for the OAR are inclined toward these common fracture sites.6,7 Because of the OAR's predisposition toward more common fractures, the proper diagnosis of isolated posterior malleolar via physical examination is difficult, and establishing the diagnosis via standard radiographs has shown to be more difficult than most other ankle fractures.6,7,14,17

This case highlights the importance of completing a thorough history and performing a thorough physical examination in order to formulate the most likely diagnosis after a unique injury such as the one sustained by the subject of this case. In this case, exact details of foot position at impact were not entirely clear. However, a common mechanism of injury for posterior malleolar fractures includes extreme plantar flexion of the foot combined with an axial load such as may occur with slipping or falling.17 Additionally, falls from a height of greater than 4 feet increase the risk for major injuries such as fractures in young active females.18 In this case the information from the history, along with physical examination findings of posterior and posteromedial ankle tenderness, the presence of significant edema and ecchymosis, and the functional limitations, made the therapist consider the differential diagnosis of an isolated posterior malleolar fracture.

If a posterior malleolar fracture is suspected, plain radiographs may be insufficient to rule out this fracture.14,17 The CT scan, therefore, has been advocated as the modality of choice to accurately assess for the presence of an isolated posterior malleolar fracture. When plain film radiography was compared to CT there was only a sensitivity of 63%.14 Haraguchi et al15 reviewed both plain film and CT imaging with posterior malleolar fractures and classified the fractures into three categories: Type I, a fracture through the posterior lateral portion of the tibia; Type II, a fracture through posterior lateral portion and into the medial malleolus; and Type III, one or more small shell fractures of the posterior lip. This classification was proposed because CT imaging allowed better visualization of the fracture, including the presence of small fragments.14,15,17 Association with posterior subluxation/dislocation of the talocrural joint was 30% for type I, 60% for type II and 11% for Type III fractures. In this case, the patient had a type I posterior malleolar fracture with less than 25% of the joint surface affected, with no talocrural subluxation (Figure 3) and was thus treated with cast stabilization.

While patients who have sustained isolated posterior malleolar fractures have responded well to non-surgical and surgical treatment, long-term subjective function has been shown to be less favorable when compared to outcomes following other fractures of the ankle.13,19 If the fracture encompasses greater than 25%-33% the joint surface then surgery is usually indicated.12,13,15,19-21 Fractures that involve greater than 25% of the joint surface tend to have slightly worse outcomes (ROM, pain and functional outcome measures).5 However, surgical fixation has allowed for earlier weight bearing when compared to conservative treatment. Early weight bearing has been shown to potentially improve outcomes with internal fixation of ankle fractures.20-23 In the presence of additional fractures or multiple fragments, fixation may be necessary for overall ankle stability.

This case report presents the process used for differential diagnosis of a sub-acute traumatic injury to the ankle of a female cadet. It is important to consider all aspects of the patient evaluation process collectively instead of using individual components of the examination in isolation. For example, concluding that this patient did not need imaging because the OAR was negative would have been a mistake. Instead, each part of the history and physical examination is a piece that needs to be grouped together to be considered collectively to develop a “clinical picture” in order to form a list of most likely diagnoses until a definitive diagnosis is achieved.
CONCLUSION
This case report illustrates the examination and clinical decision making process that led to the diagnosis of an isolated posterior malleolar fracture of the ankle, a fairly unique injury. While the findings of the OAR did not indicate that a fracture was likely, plain radiographs were obtained due to the combination of other examination findings (i.e., a fall from a considerable height, significant edema and ecchymosis, location of tenderness, and lack of pain with ligamentous testing). If a posterior malleolar fracture is suspected, visualization of a fracture may be evident on the lateral view of a radiograph, but a CT scan is of greater value for diagnosis of this fracture.

REFERENCES
ABSTRACT

Study Design: Case Report

Background: Femoral acetabular impingement (FAI) has been implicated in the etiology of acetabular labral tears. The rehabilitation of younger athletes following arthroscopic surgery for FAI and labral tears is often complex and multifactorial. A paucity of evidence exists to describe the rehabilitation of younger athletes who have undergone arthroscopic hip surgery.

Case Presentation: This case report describes a four-phase rehabilitation program for a high school football player who underwent hip arthroscopy with a labral repair and chondroplasty.

Outcomes: The player returned to training for football 16 weeks later and at the 4 month follow-up was pain free with no signs of FAI.

Discussion: There is little evidence regarding the rehabilitation of younger athletes who undergo arthroscopic hip surgery. This case study described a four phase rehabilitation program for a high school football player who underwent hip arthroscopy and labral repair. The patient achieved positive outcomes with a full return to athletic activity and football. The overall success of these patients depends on the appropriate surgical procedure and rehabilitation program.

Key Words: Femoral acetabular impingement (FAI), hip, hip impingement

Level of evidence: 4-Case report
BACKGROUND
Labral tears of the hip commonly occur with FAI (Femoral acetabular impingement).1-5 Recently, FAI has been diagnosed more frequently in younger active individuals with an etiology that is not well understood.1 In fact, Ochoa et al looked at the radiographic evidence of 155 young active patients’ 18-50 years of age with complaints of hip pain presenting to primary care and orthopaedic clinics. In the aforementioned study it was reported that 87% of the subjects had evidence of FAI.1

FAI is commonly classified as a cam-type, pincer-type, or mixed cam-pincer. Cam-type impingement occurs when the femoral head is abnormally shaped and contacts a normal acetabulum. The abnormally shaped “bump” abuts the acetabular rim creating shearing and compressive forces that may result in tearing of the acetabular labrum and chondral injury to the femoral head and/or acetabular rim.1,2,6

Research has identified that males have a predilection for cam-type impingement.7,8 Reichenbach et al conducted a cross-sectional study on 1,080 young asymptomatic male subjects using magnetic resonance imaging (MRI) and found a cam-type deformity in every fourth male and in every second male with decreased hip internal rotation.8 Allen et al also found a prevalence of 77.8% bilateral cam-type impingement in a sample of 113 symptomatic males.9 Pincer-type impingement occurs when the acetabular rim is abnormally shaped, deep, or retroverted and contacts a normally shaped femoral head.1,7 This “over-coverage” often results in labral degeneration and tearing.1,2,10,11 Pincer-type impingement is more common in females.10 Reichenbach and colleagues conducted an MRI cross sectional study on 80 young females (18-19 years-old) and found a greater prevalence of pincer-type deformity compared to cam-type deformity.12 When both cam & pincer-type deformity occur it is commonly classified as mixed. Studies have shown that mixed impingement can occur in 57-85% of younger individuals.2,7,13

Damage to the acetabular labrum from FAI can affect overall hip function. The acetabular labrum has various functions including enhancing joint stability, shock absorption, proprioception, joint lubrication, pressure distribution, deepening of the joint, and creating a seal.14,15 Labral tears occur most frequently in the anterior quadrant.14 Researchers have postulated that the anterior labral region may be more susceptible to tears due the following three factors: (1) the anterior labrum has a low vascular supply which results in poor healing; (2) this region is mechanically weaker than other regions; (3) the anterior labrum may experience higher loads and shear forces than other regions of the labrum.14-16 The consequence of hip labral damage is destabilization of the hip joint and increased loading of the articular cartilage which may lead to degenerative joint disease.14 McCarthy et al have proposed a series of events that may lead to intraarticular joint disease: (1) traction or FAI that excessively loads the acetabular labrum at the extremes of joint motion, (2) fraying of the articular margin of acetabular labrum, tearing along the articular margin of the acetabular labrum, (3) delamination of the articular cartilage from the articular margin adjacent to the labral lesion, and (4) more global labral and articular cartilage degeneration.14,15

Arthroscopic surgery for FAI & labral tears has become an accepted procedure for many athletes of varied ages. Due to the emergence of new surgical techniques and advances in diagnostic capabilities there is a gap in the research regarding rehabilitation of younger athletic individuals following hip arthroscopy. The rehabilitation of these athletes can be complex and requires a systematic approach to ensure a successful return to activity. A recent search of the literature revealed various approaches to rehabilitation in which most of them described a four-phase rehabilitation approach, however all but one of the articles were narrative reviews.17-21 One case report was found that described the four phase approach for a 25-year-old professional football athlete who underwent arthroscopic debridement and labral repair.21 Due to the paucity of literature, there is a need for a more detailed description of this four phase rehabilitation approach with younger individuals. The purpose of this case report is to describe the rehabilitation program for an 18 year-old athlete who underwent arthroscopic surgery for left hip mixed FAI with an anterior superior labral tear.

CASE DESCRIPTION
Patient History
The patient was an 18-year-old male high school athlete who underwent arthroscopic surgery for a left
hip mixed FAI with an anterior superior labral tear in March 2011. The patient participated in high school football (at the free-safety position) and reported an insidious onset of left hip and groin pain for one year prior to formal diagnosis. The patient initially had intermittent “groin” pain and “clicking” during and after physical activity which eventually became more severe. As the severity increased, the patient began to feel anterolateral hip pain and had an observable antalgic gait. Aggravating activity included running, twisting or turning, sit to stand transitions, and stair ambulation. The patient managed his pain with ice and heat; however, increasing pain prompted him to see an orthopaedic surgeon. Diagnosis was confirmed by MR arthrogram (Tesla 3T from Phillips) which revealed a left mixed cam-pincer femoroacetabular impingement with an anterosuperior labral tear. The patient's symptoms were recalcitrant to physical therapy, activity modification, and medical management. Given the persistence of symptoms, lack of success with conservative management, and inability to participate in physical activity and sports without pain, he elected to undergo surgical intervention. The surgical intervention included an acetabular and femoral head osteoplasty & chondroplasty, a capsular synovectomy, and an anterior superior labral repair via two arthroscopic portals. The patient's primary goals were to return to pain-free physical activity and begin college football in the fall.

INITIAL EXAMINATION
The patient was seen for initial examination two days after surgery. The patient appeared to be a healthy 18-year-old male with a mixed endomorphic-mesomorphic build (Body mass-92.53 kg, Height-182.9 cm, Body mass index-27.7).

Functional Status
This patient came to the appointment ambulating on two crutches with “touch down” weight bearing precautions, which were to be continued for 6 weeks from the date of surgery in order to protect the labral repair site. The patient was restricted from flexing the hip beyond 90 degrees for the first 3 weeks postoperatively to protect the healing joint capsule. The patient was instructed to use a Continuous Passive Motion Machine (CPM) from 0-90 degrees of hip flexion for 4-6 hours per day for the first 4 weeks based on the surgeon's goal of enhancing joint motion and nutrition.

System Review
A review of the patient's history and the interview revealed no current or prior medical issues that would impede rehabilitation. Family history was negative for any cardiovascular risk factors or family history of hip pathology. Inspection of the incision site revealed adequate healing with the steri-strips intact over the mid anterior and anterolateral portals. A neurovascular screen of the lower extremity revealed no significant findings.

TEST AND MEASURES
Pain
During the initial examination, an 11-point numerical pain rating scale (0 no pain to 10 the worst pain imaginable) was used to elicit an objective ranking of the patients pain level.23,24 The patient reported a 2/10 pain at rest, 4/10 pain with prolonged ambulation, and an increase to 5/10 with combined hip flexion & internal rotation. The patient's overall pain was decreased to a 2/10 pain with pain medication (Vicodin).

Gait
A general gait assessment was conducted for crutch ambulation. The patient was able to ambulate using two crutches with a step through gait pattern and touch down weight bearing on the left lower extremity.

Range of Motion
The patient's hip, knee, and ankle range of motion (ROM) were tested both actively and passively as described by Norkin & White.25 Bilateral lower extremity measurements were WNL and symmetrical with the exception of the left hip. The patient was apprehensive with actively moving the left hip but agreed to assessment of passive range of motion (PROM). PROM of the left hip revealed the following: flexion 90 degrees, internal & external rotation 30 degrees, abduction 25 degrees, adduction 10 degrees, and hip extension 0 degrees. Motions were limited due to the patient's pain level.

Muscle Performance
The patient's muscle performance was measured using manual muscle testing as described by Hislop
Muscle Length Assessment
Muscle length was tested on the patient's lower extremities. The patient's right lower extremity tested positive for the following: Ober's test for iliotibial band length and 90/90 test for hamstring muscle length. The patient's left lower extremity tested positive for the following tests: Ober's test, 90/90 hamstring test, and Ely's test for rectus femoris length. The Thomas test was not performed on the left hip due to patient's level of discomfort with hip extension.

Palpation
Palpation of the left hip musculature was assessed using a 5 point pain scale (Grade 0-4) as described by Hubbard & Berkoff. The grading criterion is as follows: Grade 0: no tenderness; Grade I: mild tenderness without grimace or flinch; Grade II: moderate tenderness plus grimace or flinch; Grade III: severe tenderness plus marked flinch or withdrawal; Grade IV: unbearable tenderness, patient withdrawals with light touch. Palpation of the patient's hip revealed grade II (moderate) tenderness along the iliacus, common iliopsoas tendon, adductors, and muscle belly of the tensor fascia lata. The patient also had grade I (mild) palpable tenderness around the surgical portals and proximal iliotibial band. There was no palpable tenderness of the hip external rotators.

Assessment
At the time of examination, the patient was two days post-surgical with the prescribed ROM and weight bearing precautions. The posture and ROM assessment revealed a compensatory right trunk shift away from the left lower extremity and decreased left hip ROM in all planes due to pain and apprehension by the patient. Strength & muscle length testing revealed general weakness and decreased length of the hip musculature which may have been linked to weight bearing precautions, disuse, and pain. Palpation also revealed tenderness in the anterior hip musculature. In the authors experience, anterior hip tenderness is a common and expected clinical finding following this type of hip surgery.

Plan of Care
The rehabilitation program (Table 2, a & b) was based on the hip arthroscopic post-operative protocol from the referring surgeon who utilizes the four phase rehabilitation program described in this case report. Trunk stabilization and general lower kinetic chain exercises were integrated into the program consistent with the regional interdependence model.

POST-OPERATIVE REHABILITATION
Phase I: Initial
The focus of phase one was to protect the repaired tissue, restore ROM, control pain & inflammation, and restore neuromuscular control. Phase I typically last from 4 to 6 weeks depending on the specific details of the surgical procedure and weight bearing guidelines. The recommended criteria for progressing from phase I to phase II included full weight bearing, minimal pain with phase I activity, ROM ≥ 75% of the uninvolved side, and proper muscle firing patterns (e.g. proper muscle recruitment with activity). Recommended precautions include: avoiding hip flexor pain and following ROM & weight bearing restrictions.

During this phase, physical therapy interventions included the following ROM activities: upright bike riding (foot straps used), ankle pumps, towel slides, prone lying, quadruped rocking, and standing IR/ER with chair (Figure 1), assisted active and passive range of motion within post-operative guidelines in all planes of motion. Prone lying, which has been recommended

<table>
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<th>Table 1. Muscle performance testing</th>
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<td>Muscle Groups Tested</td>
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<td>----------------------</td>
</tr>
<tr>
<td>Hip flexors</td>
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<tr>
<td>Hip extensors</td>
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<tr>
<td>Hip abductors</td>
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<tr>
<td>Hip adductors</td>
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<tr>
<td>Hip external rotators</td>
</tr>
<tr>
<td>Hip internal rotators</td>
</tr>
<tr>
<td>Knee extensors</td>
</tr>
<tr>
<td>Knee flexors</td>
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<tr>
<td>Ankle Dorsiflexors</td>
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<td>Ankle Plantarflexors</td>
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to prevent hip flexion contractures, was also prescribed. Physical therapy also consisted of isometrics for the hip and leg (e.g. quad sets, hamstring sets), resisted prone IR/ER, active movement in three way leg raises (abduction, adduction, and hip extension), sidelying clamshells, double leg bridges, and leg press, initiated at week 6. In some cases, leg press may be introduced earlier but the surgical protocol should dictate such progressions. Basic core activities (e.g. the abdominal drawing in maneuver) were introduced

<table>
<thead>
<tr>
<th>Table 2. Four phase rehabilitation program.</th>
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<tr>
<td>Phases of Rehabilitation</td>
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<tr>
<td><strong>Phase I: Initial</strong></td>
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<tr>
<td><strong>Focus</strong>: protect the repaired tissue, restore ROM, control pain &amp; inflammation, and restore neuromuscular control.</td>
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<tr>
<td><strong>Criteria for Phase II</strong>: full weight bearing, minimal pain with phase I activity, ROM ≥ 75% of the unininvolved side, and proper muscle firing patterns.</td>
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<td><strong>Precautions</strong>: avoid hip flexor pain and follow ROM &amp; weight bearing restriction.</td>
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| **Range of Motion**: upright bike riding, ankle pumps, towel slides, prone lying, quadruped rocking, and standing IR/ER with chair. |
| **Strengthening**: isometrics for the hip and leg (e.g. quad sets, hamstring sets), resisted prone IR/ER, three way leg raises (abduction, adduction, and hip extension), sidelying clams, double leg bridges, and leg press. |
| **Stretching**: gluteals, hamstrings, and piriformis, hip flexor & adductor stretching began at 4 weeks. |

**Manual Therapy**: passive range of motion and joint mobilization began at 5 weeks

**Home Program**: daily prone lying and passive range of motion.

| **Phase II: Intermediate**                      |
| **Focus**: protect the repaired tissue, restore ROM, restore a normal gait pattern, and progressively increase muscle strength. |
| **Criteria for Phase III**: pain-free gait, full ROM, hip flexion strength >60% of the unininvolved side, all other hip motion (abd, add, ext, IR, ER) strength >70%. |
| **Precautions**: avoid forceful or ballistic stretching, no treadmill, and prevent hip flexor and joint irritation. |

| **Range of Motion**: phase I activity |
| **Strengthening**: phase I activity with the addition of closed kinetic chain (CKC) exercises which included: bilateral squats, side stepping, and ¼ lunge (sagittal & frontal plane). |

**Abdominal Core**: basic core strengthening (e.g. planks) exercises.

**Stretching**: phase I stretching continued with the addition of self-myofascial release with the foam roll.

**Cardiovascular**: elliptical & stationary bicycle

**Manual Therapy**: passive range of motion and joint mobilization

**Home Program**: phases I & II activity and the addition of cardiovascular conditioning with the elliptical and stationary bike.
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<tr>
<th>Phases of Rehabilitation</th>
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| **Phase III: Advanced** | **Focus:** further restore muscular endurance & strength, improve cardiovascular endurance, and optimize neuromuscular control, balance, and proprioception.  
**Criteria for Phase IV:** hip flexion strength >70% of the uninvolved side, all other hip motion (abd, add, ext, IR, ER) strength >80% of the uninvolved side, cardiovascular fitness equal to pre-injury level, and ability to participate in controlled initial agility drills.  
**Precautions:** avoid forceful or ballistic stretching, no treadmill, prevent hip flexor and joint irritation, and avoid contact sports.  |
|  | **Range of Motion:** phases I & II activity  
**Strengthening:** phase II activity with the addition of multidirectional closed kinetic chain (CKC) exercises and basic movements on the TRX© suspension training system were introduced including (e.g. single leg squats, side lunges)  
**Abdominal Core:** progressive core exercises using the TRX© suspension training system (e.g. suspended planks, gluteal bridges).  
**Stretching:** basic stretching and self-myofascial release techniques were continued with emphasis on the rectus femoris, hip flexors, tensor fascia lata, and adductors.  
**Cardiovascular:** elliptical & stationary bike  
**Manual Therapy:** passive range of motion and joint mobilization  
**Home Program:** phases I to III activity, continue cardiovascular conditioning with the elliptical and stationary bike.  |
| **Phase IV: Sports Specific** | **Focus:** for the patient to work towards returning to competition.  
**Criteria for Phase IV:** hip flexion strength >85% of the uninvolved side, full pain-free ROM, ability to perform sports specific drills at full speed, and successful completion of any sports related testing.  
**Precautions:** pain free activity  |
|  | **Range of Motion:** phases I to III activity as needed.  
**Strengthening:** phases I to III activity as needed. Begin sports specific activity including low level plyometrics, multi-directional agility drills, and circuit training.  
**Abdominal Core:** advanced core strengthening exercises on the TRX© (e.g. mountain climbers).  
**Stretching:** phases I to III activity as needed with the addition of a dynamic warm-up.  
**Cardiovascular:** elliptical, stationary bike, & progressive jogging (12 weeks)  
**Manual Therapy:** passive range of motion and joint mobilization as needed.  
**Home Program:** phases I to III activity and the introduction of jogging for cardiovascular conditioning.  |
During this phase, gentle stretching for the gluteals, hamstrings, and piriformis were also done to improve muscle length while respecting mobility precautions. Hip flexor & adductor stretching was initiated at post-operative week 4 in order to avoid any myotendinous irritation. In the authors’ experience, early stretching and increased activity of the hip flexors and adductors can lead to inflammatory type pain at the tendons. These findings are supported by other authors who have reported similar results. Manual therapy focused on restoring mobility to the hip joint through passive range of motion and joint mobilization. It has been recommended to passively move the hip through all motions including circumduction to prevent intracapsular adhesions. Recently, Beck found adhesion formation that occurs between the joint capsule and the resected femoral neck may lead to soft tissue impingement by squeezing the acetabular labrum during hip flexion and internal rotation. These findings support the initiation of early passive hip motion and the monitoring of post-operative groin pain. Joint mobilization began at post-operative week 5 and consisted of anterior to posterior graded mobilization and long-axis distraction. A portion of each therapy session consisted of soft tissue mobilization, passive range of motion (PROM), and graded joint mobilization. PROM activity should be pain free and absent of any signs of impingement (e.g. pinching sensation) especially with circumduction.

The patient’s home exercise program also included daily prone lying and passive range of motion. Also, the patient’s family was taught various assisted pain free passive hip movements which included passive hip flexion to 90°, circumduction (Figure 2 a,b,c), internal rotation, and external rotation, to be performed.
three times per day. The patient was seen for physical therapy an average of two times per week. After 6 weeks of physical therapy, the patient had met all criteria and was progressed to Phase II.

**Phase II: Intermediate**
The focus of phase II was to protect the repaired tissue, restore ROM, restore a normal gait pattern, and progressively increase muscle strength. Phase II typically begins between 4 to 6 weeks post-surgery depending on the surgical procedure and weight bearing guidelines. The recommended criteria for progressing from phase II to phase III included pain-free gait with full-weight bearing, full ROM, hip flexion strength >60% of the uninvolved side, all other hip motion (abd, add, ext, IR, ER) strength >70% of the uninvolved side. Recommended precautions include: avoiding forceful or ballistic stretching, no use of the treadmill, and preventing hip and joint irritation.

The patient quickly progressed through this phase. Physical therapy included basic ROM & strengthening activities continued from Phase I with the addition of the elliptical trainer and mini trampoline marching for cardiovascular conditioning. The patient's program also included a progression of closed kinetic chain (CKC) exercises which included: bilateral squats, side stepping, and ¼ lunges. These movements were limited to the sagittal and frontal plane in order to avoid increased stress in the hip. Consistent with the regional interdependence model, core strengthening (e.g. planks) exercises were introduced during this phase given the interrelationship between proximal stability and the lower kinetic chain. Balance activity was introduced which included single leg stance on the ground and foam pad. Stretching activities from Phase I continued with the addition of self-myofascial release with the foam roll.

Manual therapy by the physical therapist focused on the soft tissue management of the anterior hip musculature with emphasis on the iliopsoas, tensor fascia lata, and adductors. These muscles had become overactive and shortened which was confirmed upon phase II re-examination of muscle length (e.g. Thomas test, etc.). Manual treatment also included graded anterior to posterior and long-axis distraction joint mobilization, and PROM.

The patient's home exercise program included Phase I & II activity with the addition of cardiovascular conditioning with the elliptical and stationary bike. At 8 weeks post-operative, the patient met all criteria and was progressed to Phase III.

**Phase III: Advanced**
The focus of Phase III was to further restore muscular endurance & strength, improve cardiovascular endurance, and optimize neuromuscular control, balance, and proprioception. Phase III is typically started between 6 to 8 post-operative weeks depending on the patient status. The recommended criteria for progressing from phase III to phase IV includes hip flexion strength >70% of the uninvolved side, all other hip motions (abd, add, ext, IR, ER) strength >80% of the uninvolved side, cardiovascular fitness equal to pre-injury level, and ability to participate in controlled initial agility drills. Recommended precautions include: avoiding forceful or ballistic stretching, no use of the treadmill, preventing hip flexor and joint irritation, and avoiding contact sports. In the authors experience, the treadmill is often withheld due to the change in gait (e.g. stride length) that may occur. Moreover, the authors believe that this change in gait may cause increased demands to the hip musculature and surgical site.

During this phase, the patient continued the basic ROM & strengthening activities in phase II with the addition of more advanced activity. Multidirectional closed kinetic chain (CKC) exercises and basic movements on the TRX® Suspension training system (TRX®) (Fitness Anywhere LLC, San Francisco, CA) were introduced including single leg squats (Figure 3) and side lunges. Exercise variables that were manipulated include repetitions, speed of movement, and surface stability. More progressive core exercises were performed including suspended planks (Figure 4) and gluteal bridges (Figure 5) on the TRX®. The aforementioned TRX® exercises provide an alternative to traditional bodyweight exercise. However, if such equipment is unavailable, it is not unreasonable to assume traditional bodyweight activity or use of a physioball could be just as effective. Alternatives for the lower extremity exercises mentioned above may include single leg squats and side lunges with dumbbells and alternatives for the core exercises may include
planks or glut bridges on a physioball. Balance activity was progressed using the BOSU® (Team BOSU, Canton, OH). The authors utilized more qualitative assessment to measure balance (e.g. time) and neuromuscular control (e.g. use of ankle & hip strategy). Basic stretching and self-myofascial release techniques were continued with emphasis on the rectus femoris, hip flexors, tensor fascia lata, and adductors. Manual therapy continued with soft tissue management of the hip musculature and graded joint mobilization. Graded joint mobilization was continued in order to maintain joint mobility.

The patient’s home exercise program included Phase III activity with the elliptical & stationary bike for cardiovascular conditioning. At 12-weeks post-operative the patient met all criteria and was progressed to Phase IV.

**Phase IV: Sports Specific**

The focus of Phase IV is for the patient to work towards returning to competition. This phase typically begins between 8 to 16 weeks depending on the patients status. The recommended criteria for progressing from Phase IV to unrestricted sports activity includes: hip flexion strength >85% of the involved side, full pain-free ROM, ability to perform sports specific drills at full speed, and successful completion of any sports related testing. Recommended precautions at this phase include maintaining activities at the pain free level.

During this phase, the patient continued the muscle performance activities from Phase III with the addition of more advanced activity. The patient began sports specific activity including low level plyometrics (e.g. jump rope), multidirectional agility drills (e.g. ladder drills), and circuit training. Examples of the exercise variables manipulated included speed of movement, planes of motion, and work to rest ratios. Emphasis was placed on proper lower kinetic chain mechanics through the hip, knee, and foot during multidirectional movements. This ensured that the lower extremity was functioning as an efficient interdependent system during ballistic activity.

Progressive jogging activity began at post-operative week 12 with a combination of distance running and
short sprints. Advanced core strengthening was introduced including advanced TRX® exercises such as mountain climbers (Figure 6 a,b). An alternative would be to do this movement with hands on the ground or on a bench. Advanced balance activity was introduced by challenging the patient's visual, vestibular, and somatosensory systems. Examples of activities included ball tossing on unstable surface (air filled disc), single leg balance with eyes closed, and diagonal eye and head movements while standing on the BOSU® ball. Dynamic warm-ups were introduced prior to activity and basic stretching and self-myofascial release techniques for the lower extremity were continued after physical activity. The overall focus was to prepare the patient for advanced training by improving dynamic balance and eccentric control. As needed, manual therapy was performed to manage any residual soft-tissue or joint restrictions.

OUTCOMES

Discharge
The patient was discharged in August 2011 after completing 16 weeks of physical therapy with reports of 0/10 pain with activities of daily living, weight training, and sports activity (e.g. jogging, football drills). The left hip had full pain-free motion and all hip & knee manual muscle tests were graded a 5/5. The authors did not have access to a hand held dynamometer or isokinetic device which would have provided a more objective measurement of the patients muscle strength. Muscle length was normal except for mild hip flexor tightness confirmed with the Thomas test. The patient had adequate neuromuscular control with single leg and multidirectional activity demonstrated by little compensatory movements at the hip, knee, and ankle. This patient met all goals for Phase IV except for sports specific testing thus was immediately scheduled to begin advanced sports specific and agility training in preparation for the next football season. This included sports specific testing and creation of a periodization program.

Follow-Up (1-month)
At the one month follow-up, the patient reported pain-free sports specific training, weight lifting, agility training, and jogging. The re-examination revealed the same findings at discharge with normal hip ROM, hip muscle strength 5/5, and no signs of hip impingement with the Flexion-Adduction-Internal Rotation (FADIR) test. The patient still had adequate neuromuscular control with single leg squats and multidirectional movements. The patient had mild muscle length deficits in the hamstrings and hip flexors. The patient's home flexibility program was reviewed including self-myofascial release techniques utilizing a foam roll.

Follow-Up (4-months)
At the four month follow-up, the patient had reduced his body mass to 83.91 kg and presented with a mesomorphic build. The patient had also returned to full pain-free unrestricted activity that included running, power lifting, and football training at college. The re-examination revealed normal active and passive range with all hip motions and no hip impingement signs with the FADIR test. All hip & knee manual muscle tests were graded at 5/5 and muscle length...
was normal throughout the hip and lower extremity. The patient also had adequate neuromuscular control with full squats, single leg balance, single leg squats and multiplanar movements.

DISCUSSION
The presence of FAI in younger football players may be more prevalent than previously suspected. In fact, Kapron et al looked at the radiographic prevalence of FAI in 65 male collegiate football players (age, 21 ± 1.9 yrs) and found that 95% had at least one sign of cam or pincer impingement and 57% had signs of both (mixed).3 Despite the advances in diagnostics and surgical interventions there still is a dearth in the literature addressing the rehabilitation of these individuals. Currently only one case study was found that examined the rehabilitation of a 25 year-old professional football player.22

This case report outlined a four phase rehabilitation program for a high school football athlete who underwent arthroscopic surgery for a mixed FAI impingement and an anterosuperior labral tear. The patient achieved successful outcomes with a full return to athletic activity and football after 16 weeks of structured rehabilitation. The overall success of these patients depends on the appropriate surgical procedure and rehabilitation program. This is supported by findings from Philippon and colleagues who examined the outcomes of 45 professional athletes who underwent hip arthroscopic FAI decompression, labral repair, and prescribed rehabilitation.11 At the average 1.6 year follow-up, 42 (93%) of the athletes had returned to professional competition.11

It is critical for the clinician to understand that each phase in the rehabilitation process builds upon the previous, which allows for a safe progression. Early phases of rehabilitation should emphasize hip PROM to avoid intraarticular adhesions and isolated muscle strengthening in order to regain appropriate neuromuscular control.19 Later phases should emphasize dynamic muscular control and preparation for sports specific activity.19 Each phase should be criterion based in order to consider the patient’s individual healing process and any barriers (e.g. co-morbidities) that may be present. The clinician may want to standardize their muscle performance testing procedures for each phase. The use of MMT is often subjective and may be difficult to assess (e.g. 60 vs. 70%) between phases.30,31 If available, the use of dynamometry or isokinetic strength testing may provide a more objective interpretation.31 The authors also recommended the use of an objective functional outcome measure such as the Lower Extremity Functional Scale (LEFS) at the initial consult and at discharge to provide a more comprehensive outcomes assessment. This was a limitation of the current case report.

For younger football players, future studies should focus on risk factors for the development of FAI that may be related to position, training methods, and maturation. Future research should also focus on the outcomes of the four phase rehabilitation program for younger athletes in specific sports including: dance, hockey, and soccer.

The outcomes of this case study, using the four phase protocol, were based on the authors' clinical experience with this type of surgery. There is a definite need to establish evidence based specifics regarding the timing and implementation of the four phase protocol or any interventions used for the management of post-operative FAI. Such evidence would help to guide the clinician in developing effective and sports specific rehabilitation programs.

CONCLUSION
There is little evidence regarding the rehabilitation of younger athletes who undergo arthroscopic hip surgery. This case report described a four phase rehabilitation program for a high school football player who underwent hip arthroscopy and labral repair. The success of the rehabilitation program was based upon a systematic progression and introduction of interventions at the appropriate time.

REFERENCES


ABSTRACT

Background: The management of the pediatric patient with an Anterior Cruciate Ligament (ACL) rupture is evolving towards earlier reconstruction. The rehabilitation progression and outcomes for skeletally immature individuals undergoing ACL reconstruction (ACL-R) are not well described in the literature. Differences in surgical procedure, age related physiology, and emotional maturity may have a significant impact on recovery and return to sports. The purpose of this case report is to present the rehabilitation and outcome of a skeletally immature patient that underwent an all-epiphyseal ACL-R, highlight important considerations in the rehabilitation process and present topics for future research.

Case Description: Single subject case report of an 8 year-old boy who underwent all epiphyseal ACL-R after complete ACL rupture.

Outcomes: The patient was able to achieve at least 90% strength symmetry and pass all necessary functional criteria to return to sports by 9 months post surgery. Two year follow up data indicated that the patient was able to make a full return to previous level of athletic activity, as well as maintain lower extremity strength and power over time.

Discussion: Objective outcome measures, rehabilitation protocols and time frame for return to sports for skeletally immature patients following physeal sparing or all epiphyseal ACL-R are not well described in the literature. This case report outlines objective measures of strength and functional recovery in a patient from this unique population. As ACL-R in the skeletally immature patient is studied more, new information on rehabilitation progression and outcomes may alter the rehabilitation program and timeline for return to unrestricted activity.

Key words: Anterior cruciate ligament, pediatric, rehabilitation, return to sports

Level of Evidence: 4, Case Report
BACKGROUND

Intrasubstance Anterior Cruciate Ligament (ACL) tears are being reported with increasing frequency in the pediatric skeletally immature population.1-2 Although there is no consensus regarding non-operative versus operative treatment, delaying treatment until closer to skeletal maturity has been associated with chronic instability leading to chondral and meniscal injuries.3-8 Traditional adult ACL reconstruction (ACL-R) techniques are not advisable in this population due to the possible risk of growth disturbance via disruption of the physis, commonly referred to as the growth plate.9 The physes of the distal femur and proximal tibia display extremely rapid growth during the adolescent growth spurt; with the distal femur contributing 40% and proximal tibia contributing 27% of the overall growth of the lower extremity.10-11 The femoral attachment of the ACL is only a few millimeters from the distal femoral physis and traditional tunnels used for ACL reconstruction in adults cross the physis obliquely and eccentrically.12-13 The tibial physis, while more distant from the tibial attachment, is also often crossed with the tunnels used in most standard adult ACL-R techniques. Tensioned grafts, rigid graft fixation, bone blocks that cross the physis and large drill holes in the physis have all been shown to increase the risk of causing a disturbance in the growth of the physis. This could lead to angular limb deformity or length disparity.1-2

Multiple techniques for surgical stabilization of the skeletally immature ACL deficient knee have been described.1-2 Recently an all epiphyseal ACL-R technique was described, that completely avoids the growth plates while still placing the ACL graft in the anatomical footprint of both the tibial and femoral attachments.9 This approach theoretically minimizes the risk of any growth abnormality due to surgery.

It is well recognized that the rate of ACL injury in the skeletally immature population is rising and with advancing surgical techniques there is a resulting increased need for post-operative physical therapy in this population.2-3 Physical rehabilitation from ACL-R in the adult population is well studied. Numerous authors have reported on successful outcomes and have identified objective performance data for rehabilitation progression and return to sports participation timeframe.14-16 However, research studying the outcomes of the skeletally immature patient after ACL-R is sparse and it remains unclear if these same recommendations and outcomes for the skeletally mature population apply in the pediatric population.3

Due to several key differences in the operative technique and age related tissue healing characteristics, modifications to the accepted evidence based rehabilitation scheme for adults are often utilized.17 Furthermore, cognitive, emotional and behavioral factors specific to the pediatric patient must be considered and can have a significant impact on the decision making process to elect surgical management and the rehabilitation program afterward.

The purpose of this case report is to present the rehabilitation and outcomes for an 8 year-old boy that underwent an all epiphyseal ACL-R. His experience will be used to highlight important considerations in the rehabilitation of these patients, to provide practical tips in approach, and introduce concepts for discussion and possible future research.

CASE DESCRIPTION

Participant and History

The patient was an 8 year-old boy (height 144 cm; weight 42 kg; Body Mass Index 21 kg/m²) who injured his right knee while attempting to land from a jump in the terrain park while skiing. Upon landing, the patient remembers his right leg twisting, feeling a “pop” and immediate pain in his knee. Physical examination and subsequent magnetic resonance imaging (MRI) confirmed the diagnosis of a complete tear of the ACL. Since he was having a recurrent sense of instability following the injury and wished to continue with an active lifestyle, after considerable thought and discussion regarding the risks and benefits of operative versus non-operative management, the patient and his family elected he undergo surgical reconstruction.

Pre-operative physical therapy

The patient was referred to physical therapy prior to surgery for gait training, post-operative education, and assessment of motivation, maturity level and ability to comply with post-operative restrictions. The patient underwent gait training utilizing bilateral axillary crutches and was educated on toe touch weight bearing (TTWB) precautions, to be used immediately
after surgery. The parents and patient were also educated in proper techniques for post-operative pain management, swelling reduction techniques and an initial exercise program. During this session, he displayed a good cognitive and physical understanding of his injury and the importance of the post-operative rehabilitation involved. He took directions well, had no problems with activity restrictions and easily learned the exercises. The authors have found that these are important characteristics that help to determine if the patient is an appropriate rehabilitation candidate in order to ensure good surgical outcomes.

The patient required one pre-operative treatment session as he had already met all the following pre-operative goals: no effusion, at least 4/5 quadriceps strength with manual muscle testing, full knee extension range of motion, at least 120° of active knee flexion range of motion, independence with gait maintaining weight bearing precautions, and independence with immediate post-operative exercise instructions.

Surgical Procedure

Approximately two months after initial injury, a fellowship trained pediatric and sports medicine orthopedic surgeon performed an all-epiphyseal ACL-R with a quadrupled autologous hamstring graft, using a newly described technique. This technique adheres to the generally accepted principles of ACL-R by placing the graft in the center of the native footprint of the ACL, but theoretically minimizes the risk to the growing physis by avoiding any fixation, large drill holes, or tensioning of the graft across the physes (Figure 1). During the procedure, an intra-operative computed tomography scan with 3-dimensional reconstruction is utilized to ensure safe and accurate placement of tunnels in the distal femoral and proximal tibial epiphyses avoiding the physes and the articular surfaces.

Postoperative Intervention

After surgery the patient was placed in a hinged post-operative knee brace locked in slight hyperextension. He was instructed to remain in the brace at all times, with the exception of while bathing or in physical therapy. Specific care was taken to make sure the patient understood he needed to wear the brace while sleeping. He used a continuous passive motion (CPM) machine for up to 6 hours per day. The range of motion was initially set from 0°-30° and he was instructed to progress his movement by 5°-10° of flexion per day as his pain permitted. He was restricted to TTWB utilizing bilateral axillary crutches as he had been instructed prior to surgery. An inpatient physical therapist reviewed gait training and ensured the patient was adherent to weight bearing restrictions and safe with ambulation prior to discharge.

Formal outpatient physical therapy was initiated on post-operative day 11 and treatment was progressed based upon our all epiphyseal ACL-R post-operative protocol (Appendix 1). Our current protocol is based upon the integration of known ACL healing characteristics in the adult population and surgeon expertise. The protocol utilizes both time and criteria based...
The patient’s pain was assessed utilizing a visual analog scale where a score of 0 represents “no pain” and a score of 10 representing “worst pain imaginable”. The patient rated his pain 0/10 at the initial visit, with the worst pain being 6/10 since surgery. A moderate joint effusion was present with a difference of 0.8 cm side to side in circumference measurement. Active knee extension-flexion range of motion (ROM) was 0°-65° and passive range of motion was 0°-85°. Trace quadriceps activation was present on the involved leg and he was unable to perform a straight leg raise (SLR) without an extensor lag. The patient was started on a basic program consisting of active and passive ROM exercises, quadriceps sets and straight leg raises with the brace locked in extension. The patient was fitted with a knee compression sleeve and educated in effusion management. The patient was given specific instructions to elevate his leg for 15 minutes every hour while in school. A note was issued to his teacher detailing this program.

By the end of post-operative week 3, the patient had achieved 0-90° of passive knee ROM. He went on to recover full passive ROM of 0-150° by week 7. Quadriceps function returned quickly and the patient was able to perform a SLR with no lag during the 2nd post-operative visit. As quadriceps strength improved, the patient was able to ambulate without knee buckling or hyper-extension in stance phase. At this point, the patient had achieved sufficient muscular control of the knee to unlock his post-operative brace and begin weaning off crutches. Table 1 details the timeline for gait and brace weaning progression used for this patient. By post-operative week 5, the patient had met the proposed functional criteria of knee ROM greater than 0-100° and ability to perform a single limb squat to at least 30° of knee flexion, which would allow him to discontinue use of his hinged knee brace. However, according to the protocol, the patient is not permitted to discontinue brace usage until 6 weeks post-operative. Adherence to the use of bracing was causing the patient to become frustrated and his parents reported this was leading to some behavioral difficulties. As a compromise, the patient was allowed to ambulate without the brace at home, but was still advised to continue to wear the hinged brace when in public and at school.

Open kinetic chain knee extension and flexion exercises were held until after post-operative week 10. After that, the remainder of the progression followed the protocol of accelerated rehabilitation based on established guidelines for strengthening and dynamic stabilization training derived from guidelines following adult ACL-R.

According to the protocol, the following criteria were used for advancement to running and dynamic activity: 1) The patient should be tolerating all rehab progression with no adverse reactions 2) satisfactory

<table>
<thead>
<tr>
<th>Post-op Week</th>
<th>Brace Status</th>
<th>Weight Bearing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 0-3</td>
<td>Locked at 0°</td>
<td>Toe-Touch</td>
</tr>
<tr>
<td>Week 4</td>
<td>Open 0°-50°</td>
<td>Partial Weight Bearing (PWB)</td>
</tr>
<tr>
<td>Week 5</td>
<td>No Brace (at home)</td>
<td>FWB</td>
</tr>
<tr>
<td></td>
<td>Open 0°-90°</td>
<td>FWB</td>
</tr>
<tr>
<td>Week 6</td>
<td>No Brace</td>
<td>FWB</td>
</tr>
</tbody>
</table>

Table 1. Sequence of brace management and gait progression.
physician clinical and radiograph exam 3) less than 25% peak torque quad deficit with isokinetic testing at 180° and 300° per second and 4) less than 3 mm translation with KT-1000 (MEDmetric® Corporation, San Diego, CA) knee arthrometer testing. Formal evaluation for advancement was performed at 14 weeks post-operatively. Due to the patient’s physical size, the KT-1000 unit would not fit appropriately and therefore did not yield a reliable measurement. Thus, this criterion for advancement could not contribute to clinical decision making. Utilizing the unaffected limb as a control, isokinetic testing revealed a peak torque quadriceps deficit of 6.3% and 10.9% at 180 and 300 degrees per second respectively. The patient had been tolerating all rehabilitation exercises without complication and satisfied all physical therapy clinical testing criteria for advancement. Physician follow-up examination for progression was not scheduled until post-operative week 16. Formal physical therapy was temporarily discontinued and the patient continued performing his established home exercise program supervised by his parents. After a satisfactory physician examination, he was cleared for advancement by the physician.

The patient was progressed through running and agility exercises beginning in straight planes with double leg activities and progressing to multidirectional drills. Plyometric training began at 19 weeks post-operatively with low-level bilateral training. The therapist focused instruction of technique emphasizing limiting ground impact forces and limiting any dynamic knee valgus at takeoff or landing. As the patient demonstrated proper mechanics, the demand of plyometric training was increased from bilateral to unilateral tasks and finally to multiplanar jumps. At this point in time, the patient was fitted with a DonJoy™ Full Force functional ACL brace (DJO Global, LLC, Vista, CA). The recommendation by the surgeon is that the brace be worn with all sports activity for at least 2 years following surgery.

Progression to sports specific rehabilitation activities is typically allowed between weeks 24-36 and is dependent upon the patient satisfying the following criteria: 1) pain free with all activity thus far 2) quadriceps peak torque deficit less than 10% 3) functional hop test scores of less than 10% deficit 4) satisfactory lower extremity control and alignment during jumping task. The patient was tested at 6 months post surgery. Isokinetic testing results demonstrated a 9.3% peak torque quadriceps deficit at 180° and a 3.1% strength advantage on his operated leg at 300° per second. Functional hop testing consisted of a single leg hop, single leg triple hop, single leg vertical jump and single leg side-to-side jump. As outlined in Table 2, the patient was able to achieve at least 90% symmetry with all functional hop tests, with the exception of timed side to side hop, which was 88% symmetrical. He demonstrated excellent landing form with no valgus movement of the knee upon landing or take off, ability to cushion impact descending into approximately 20-30° hip and knee flexion upon landing and stable balance with landing.

<table>
<thead>
<tr>
<th>Functional Hop Test</th>
<th>Involved leg</th>
<th>Uninvolved Leg</th>
<th>Involved / Uninvolved</th>
<th>Percentage Deficit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Leg Jump</td>
<td>109 cm</td>
<td>101 cm</td>
<td>1.07</td>
<td>+7%</td>
</tr>
<tr>
<td>Single Leg Triple Jump</td>
<td>300 cm</td>
<td>295 cm</td>
<td>1.02</td>
<td>+2%</td>
</tr>
<tr>
<td>Single Leg Vertical Jump</td>
<td>16.5 cm</td>
<td>18.3 cm</td>
<td>.90</td>
<td>-10%</td>
</tr>
<tr>
<td>Single Leg Timed side to side Jump*</td>
<td>15 ground contacts</td>
<td>17 ground contacts</td>
<td>.88</td>
<td>-12%</td>
</tr>
</tbody>
</table>

*The patient is instructed to jump side to side as fast as they can over two lines 12” apart for a period of 20 seconds. The number of successful ground contacts the patient has on each leg within 20 seconds is counted.
Outcomes
The patient had achieved all clinical criteria necessary to return to sports within 6 months of ACL-R, however as outlined in the protocol unrestricted return to competitive sports was held until the patient is 9 months post-op. The patient had already been performing a home program that consisted of running, agility and plyometric training. He was discharged from physical therapy and advised to continue this program until his 9-month follow up with his surgeon. In the interim, he was allowed to participate in modified gym class and recess activity that did not involve any contact, as long he wore his functional ACL brace. He was advised to refrain from high-risk activities such as jumping on trampolines, skateboarding, and wrestling with his brothers. The patient returned for long term follow-up at approximately 2 years post surgery. He had returned to all recreational activities including competitive baseball and skiing. He reported no feelings of knee instability with any activity. Upon isokinetic testing patient demonstrated a strength advantage of 19.3% and 12.5% for peak torque extension force at 180 and 300 degrees per second respectively. Functional hop testing revealed the patient was able to maintain criteria of at least 90% symmetry between limbs over time. Please see Table 3 for more specific details of hop testing data.

DISCUSSION
Numerous authors have reported on successful rehabilitation after adult ACL-R and functional testing programs have been developed to help guide rehabilitation and determine readiness for return to sports participation. However, few authors have reported on similar outcomes in the pediatric population. Most outcome studies focus primarily on determination of any adverse effects on skeletal growth and define functional success based mostly on self report scales. Bonnard et al reported on 57 cases of physeal sparing ACL-R with mean age at surgery of 12.2 years and a minimum of 2 year follow-up. They found that mean time for return to sport was 11 months (range 6-18 months) and that 90% had excellent or good results based on subjective assessment using the International Knee Disability Classification (IKDC) score. The IKDC is a knee specific patient reported outcome measurement tool that has demonstrated adequate psychometric properties for use in the adult population, however it has not been validated for use in children or adolescents. Thus, the use of this scale as the primary outcome measure for this population may not yield the most reliable outcome data. Furthermore Bonnard et al do not report on specific objective outcome measures in order to demonstrate functional return of strength, power and physical ability. The case presented here demonstrates successful achievement of all return to sports criteria within 6 months of surgery and presents specific objective data about strength and functional performance throughout the recovery timeline in an 8 year old patient. This patient was able to return to sports participation at 9 months post surgery.

<table>
<thead>
<tr>
<th>Table 3. Functional Hop Test Results at 2 year post-surgical follow up</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functional Hop Test</strong></td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td>Single Leg Jump</td>
</tr>
<tr>
<td>Single Leg Triple Jump</td>
</tr>
<tr>
<td>Single Leg Vertical Jump</td>
</tr>
<tr>
<td>Single Leg Timed side to side Jump*</td>
</tr>
</tbody>
</table>

*The patient is instructed to jump side to side as fast as they can over two lines 12” apart for a period of 20 seconds. The number of successful ground contacts the patient has on each leg within 20 seconds is counted.
Although this case demonstrates a successful outcome, there are many questions regarding rehabilitation in this population that remain unanswered.

Due to the unique nature of this procedure, tissue healing characteristics are not well studied in the pediatric patient after ACL-R. Physiological healing differences may account for variations seen in rehabilitation and return to activity timelines between physeal sparing and adult ACL reconstruction. Early weight bearing is typically advocated following adult ACL reconstruction, however many surgeons advise a period of limited weight bearing for physeal sparing procedures. The recommendation for limited weight bearing in our protocol is largely based on surgeon expertise, mostly respecting the behavioral challenges that accompany this population but also acknowledging possible stress concentration across the physis, due to the location of the femoral tunnel. The pediatric patient may not possess the patience and self-control necessary to ambulate WBAT with proper gait mechanics. In such a child, excessive early weight bearing and poor gait mechanics could risk the health of the graft tissue, cause increased joint effusion and pain, and lead to lasting gait abnormalities or arthrofibrosis. Femoral tunnel placement within a few millimeters of the growth plate, while not directly disturbing the physis, may nonetheless cause stress concentration in other areas of the physis. For these reasons, it may be more beneficial to restrict weight bearing in this population in order to avoid these possible complications. The therapist familiar with this population will be able to use experience and clinical milestones such as quadriceps strength, knee stability in closed chain tasks and effusion level, to properly progress the patient’s weight bearing and gait status. These recommendations may change as physeal stress reactions and mechanisms of healing are studied further.

The physiology of strength development in the prepubescent child must also be considered during the rehab process. Prepubescent children lack circulating androgens and strength gains seen in this population are not always associated with muscle hypertrophy, as in the adult population. Neural adaptations, such as increased motor unit activation and improved motor unit coordination, are primarily responsible for strength gains in children. Quadriceps atrophy is common after ACL reconstruction and return of muscle function and strength is an essential component of rehabilitation. Although the mechanism for strength increase in children may be different, this case demonstrates full return of quadriceps strength was achieved within 6 months of surgery. This is consistent with findings of prior studies within a teenage population, however future research is needed to determine if the rate and magnitude of strength return is the same for the pediatric population.

Several emotional and behavioral factors make the rehabilitation of pediatric or adolescent patients following physeal sparing ACL reconstruction challenging to physical therapists responsible for their successful outcomes. Although pediatric specialists are well aware of these factors and well versed in coping with them, the authors have found that many children who receive physeal sparing ACL-R are being rehabilitated in classically adult physical therapy settings. Therefore the therapist treating this population, unfamiliar with these factors, may need additional guidance and assistance.

The level of emotional maturity in pediatric patients undergoing physeal sparing ACL-R must be considered as a factor during the decision making process of choosing surgical versus nonsurgical management. The parents, surgeon, and therapist must work together with the patient, to decide if the patient is mature enough to comply safely with the post-operative restrictions and motivated enough to work toward a successful outcome. Currently, this is a highly subjective process and the authors are not aware of any objective measures available to guide this decision making process. The authors currently utilize a team approach that encompasses parental opinion and observational opinion from different practitioners during physician office visits and pre-operative therapy education training. This way the team can judge in different environments and at different snapshots in time, whether the child possesses the proper level of maturity to achieve successful rehabilitation.

Maturity level also impacts rehabilitation for this population during the decision making process to discontinue use of the post-operative brace. In adult ACL-R rehabilitation the decision to discontinue the use of a brace is based solely upon physiological characteris-
tics such as graft integrity, quadriceps function, range of motion, and gait characteristics. In the rehabilitation of the child with ACL-R, the therapist must also consider other extrinsic factors as well. In this case, the patient was allowed to discontinue use of the post-operative brace earlier at home, but he was required to continue with use at school and while in public. This was done for safety considerations. It was felt that keeping the brace on in school would decrease the chances of injury from patient participation in horse-play or careless behavior on the part of his classmates. His classmates may not have remembered that the patient just had surgery without the reminder of him wearing the brace. In this way, the maturity level of not only the patient, but his peers as well, has an impact on the overall rehabilitation scheme.

ACL-R rehabilitation requires a level of dedication and commitment that can prove challenging for even the most dedicated and mature athletes. Pediatric patients participating in rehabilitation after physeal sparing ACL-R will require the therapist to be dynamic and flexible in their approach to treatment. It is important to keep the patient actively engaged in all activities while ensuring that the activity remains fresh and fun. Maintaining motivation over time can be important in enabling them to maximize their physical potential.

Parental post-operative education is one aspect of complete care that cannot be neglected. Parents must be educated in realistic expectations of the rehabilitation process in order to prevent unnecessary patient directed stress during recovery. At the author’s facility, we have occasionally seen issues arise when parents base their expectation of rehabilitation on what they see in the media about professional athletes and recovery from ACL-R. Parents can sometimes place undue pressure on the child to recover or perform. This could lead to poor outcomes or actually delayed recovery. Being aware of this possibility and addressing parent questions early is a key factor to avoiding this scenario.

While the physical therapist and parent must be knowledgeable about activity restrictions after ACL-R, it is also very important to understand what type of activities are permissible. It is important for children to have an outlet for energy, creativity, and play. Post-operative restrictions can impact many aspects of the child’s life and restoring some type of activity balance is essential for emotional and psychological wellbeing. Birthday parties, school recess, family vacations and amusement parks are some situations commonly faced by the pediatric sports medicine specialist. Parents and patients rely on the expertise of the physical therapist for recommendations that will allow the child the satisfaction of participation, but at the same time limiting risk of injury or rehabilitation complications.

CONCLUSION

The management of skeletally immature children with knee instability due to ACL rupture is evolving towards earlier ACL reconstruction. There are adverse effects associated with delaying surgical reconstruction until the patient is skeletally mature and advances in surgical techniques allow for anatomical ACL-R in the skeletally immature athlete while minimizing the risk of premature physeal closure. The rehabilitation progression in this population has some differences from traditional ACL rehabilitation programs for adults due to behavioral and physiological characteristics. Due to the lack of rehabilitation based outcome studies in the literature, the current timeline of rehabilitation progression is largely based upon integration of known ACL healing characteristics in the adult population and surgeon expertise. Future research is needed to identify the time line and magnitude of strength return, if functional performance measures used in adult ACL-R are appropriate in the skeletally immature and if so, what is the normal performance in this population. Additionally, long term objective outcome studies are necessary to determine percentage of patients that achieve successful outcomes over time.

REFERENCES


APPENDIX 1

Physeal Sparing Anterior Cruciate Ligament Reconstruction Protocol

The following protocol utilizes a blend of both criteria and timeframes as the determinants of advancement. It is recognized that many athletes will feel good relatively early in their rehabilitation and want to advance to higher level activities as a result. In spite of rapid functional progress, it is important to respect the biological component of recovery and limit advancement if the timeframe for a given healing stage has not been completed. Overall, this protocol targets return to full unrestricted activity at 9 months if all other criteria are also met. If the criteria are met sooner, the patient must restrict his/her activity level until the end of the 9th post-op month.

**Week 1:** (Visit #1 scheduled to begin one week post–op)

**Goals:**

1) Ambulation/Brace Use: **Toe-Touch Weight Bearing**
   - Post-op brace locked in full extension for ambulation
   - Sleep with brace locked in full extension

2) Maintain Full Knee Extension
3) Minimize Pain and Effusion – Compression wrap, elevation, ice
4) Good quad activation
5) Patient Education:
   - What to expect, how to maintain extension
   - CPM review (if applicable)
   - Crutches, wt bearing status
   - Hinged post-op brace education

**Exercises:**

- CPM Machine – start at 0 – 30 degrees. Increase about 10 degrees per day.
- PROM
  - a. Wall Slides Seated Active Assistive Knee Flexion
  - b. Prone Dangle
  - c. Passive resting extension with heel prop
- Patellar Mobilizations
- Quad muscle Activation (Functional E-Stim w/ Quad setting and/or Biofeedback)
- SLR x3 (Flexion, Adduction, Abduction)
- Hamstring/Calf Stretches
- Ankle Pumps
- Gait Training
- Home Exercise Program (2-3 times per day)

**Week 2 to 4:**

**Goals:**

1) Ambulation/Brace Use: Continue crutch use, **PWB brace locked in full extension**

**In Physical Therapy only, WBAT without brace for ROM, strength, & gait training**

**Continue to sleep with brace locked in full extension until end of week 4**

2) Maintain Full Knee Extension
3) Minimize Effusion and pain
4) Promote Knee Flexion:
   - 90° by end of week 2
   - 120° by end of week 4

5) Good patellar mobility
6) Fair proprioception, involved leg
7) Independent with home exercises

**Exercises:**

- As previous
- Scar Mobilization/Massage
- Proprioceptive Neuromuscular Facilitation, Progressive Resistive Exercises
- Manual/Machine resisted leg press
- Balance/Proprioception
- Isometric Knee extension 90-60°
- Stationary Bike for ROM
- Mini-Squats progress up to 90°
- Step ups
- Retro Treadmill/Stairmaster
- Core
- Hip abduction/external rotation
- Review HEP

**Weeks 4 to 16:**

**Goals:**

1) Discontinue crutch use **at 4 weeks**
2) Ambulation/Brace Use:
   - **After 4 weeks,** unlock post-op brace for ambulation (90° – progress to open) if following criteria are met:
     a. SLR without quadriceps lag (10 repetitions)
     b. Active knee flexion range to greater than angle of brace
   - **After 6 weeks,** wean and discontinue post-op brace if criteria met
     a. ROM ≥100°
     b. Single Leg Squat 30° with good knee control

4) Normalize Gait Pattern
5) Full ROM
6) Enhance Strength
7) Enhance Proprioception/Balance
8) Improve Local Muscular Endurance
9) Initiate Cardiovascular training

**Exercises:**

- As above
- Functional Strengthening
  - Proprioceptive Neuromuscular Facilitation, Progressive Resistive Exercises
  - Manual/Machine resisted leg press
  - Balance/Proprioception
  - Squats to 90 degrees
  - Single leg squats
• Step ups
• Retro Treadmill/Stairmaster
• Review Home Exercise Program (2 times per day)

12 weeks:
• May add open chain knee extension through full range

Weeks 16 to 24:
Goals:
1) Criteria to begin straight ahead running, double-leg hopping:
   Isokinetic Test - Quad Peak Torque Deficit ≤ 25% at 180°/sec and 300°/sec.
2) KT 1000 test: 15#, 20#, Quad Active, Manual Maximum (if available)

Exercises:
• Continue strength, endurance, proprioception progression
• Begin double-leg hopping, jogging, agility drills as able and if passed Isokinetic Test
• Initiate sport specific activities and double-leg plyometrics as able and if passed Isokinetic Test

Weeks 24 to 36:
Goals:
1) Gradual Return to unrestricted sports if Criteria met
   a. Pain-free running
   b. Functional Tests (>90%) and Pain free
   c. Isokinetic test
      Quadriceps Peak Torque Deficit ≤ 10%
      Total Work ≤ 10%
   d. KT 1000 test: 15#, 20#, Quad Active, Manual Maximum (if available)
   e. Cardiovascular endurance to subjective pre-morbid level

Exercises:
• Single-leg plyometrics
• Cutting/rotating drills with stutter step pattern
• High intensity aerobic/anaerobic sport specific training
• Advanced lower extremity strengthening

RETURN TO SPORTS CRITERIA
1) 90% Functional tests
2) ≥ 90 % Isokinetic Test at 180°/sec, and 300°/sec
3) Full knee ROM
4) 9 months post-op

Recommended Functional Hop Test:
• Triple Hop for distance
• Single Hop for distance
• Lateral Hop (12”x12” squares separated by 12” # of hops IN BOX in 20 seconds)
• Unilateral Vertical Jump
ABSTRACT

Purpose: To provide an overview of the characteristics and timing of rotator cuff healing and provide an update on treatments used in rehabilitation of rotator cuff repairs. The authors’ protocol of choice, used within a large sports medicine rehabilitation center, is presented and the rationale behind its implementation is discussed.

Background: If initial nonsurgical treatment of a rotator cuff tear fails, surgical repair is often the next line of treatment. It is evident that a successful outcome after surgical rotator cuff repair is as much dependent on surgical technique as it is on rehabilitation. To this end, rehabilitation protocols have proven challenging to both the orthopaedic surgeon and the involved physical therapist. Instead of being based on scientific rationale, traditionally most rehabilitation protocols are solely based on clinical experience and expert opinion.

Methods: A review of currently available literature on rehabilitation after arthroscopic rotator cuff tear repair on PUBMED / MEDLINE and EMBASE databases was performed to illustrate the available evidence behind various postoperative treatment modalities.

Results: There is little high-level scientific evidence available to support or contest current postoperative rotator cuff rehabilitation protocols. Most existing protocols are based on clinical experience with modest incorporation of scientific data.

Conclusion: Little scientific evidence is available to guide the timing of postsurgical rotator cuff rehabilitation. To this end, expert opinion and clinical experience remains a large facet of rehabilitation protocols. This review describes a rotator cuff rehabilitation protocol that incorporates currently available scientific literature guiding rehabilitation.

Key Words: Arthroscopic rotator cuff repair, rehabilitation, scientific rationale
INTRODUCTION

Rotator cuff (RC) disease is a frequent cause of shoulder pain and can result in weakness, alterations in glenohumeral kinematics, and shoulder instability in some circumstances.1 Symptomatic rotator cuff tears are thought to affect between 4% and 32% of the population and appear to be more prevalent with increasing age.2 Although patient age, activity level and tear size influence surgical decision-making, non-surgical management is frequently the preferred method of initial treatment after a rotator cuff tear. When non-surgical management of a symptomatic rotator cuff tear is not successful, operative repair is frequently necessary. Both open and arthroscopic repair of full or high-grade partial thickness rotator cuff tears have historically provided satisfactory pain relief and improvement in functional outcome scores.3-9

While successful arthroscopic rotator cuff repair requires meticulous surgical technique, it is also apparent that an individualized rehabilitation protocol supervised by skilled therapists is equally important. Rehabilitation protocols have traditionally varied considerably among providers with respect to timing of progression and appropriate therapeutic exercise.10 To this end, rehabilitation protocols are frequently based on clinical experience and expert opinion rather than scientific rationale.

The purpose of this clinical commentary, therefore, is to provide an update on current treatment strategies used in rotator cuff repair rehabilitation. The scientific rationale behind current treatment strategies is discussed where available.

ANATOMY AND BIOMECHANICS

The RC consists of the tendons of the subscapularis, supraspinatus, infraspinatus, and teres minor muscles. It functions to initiate glenohumeral joint abduction, provide internal and external rotation, and contributes to dynamic glenohumeral stability.2 It has been established that the rotator cuff is arranged histologically into five interlocking layers with distinct articular and bursal sides.11 The humeral insertion of the rotator cuff represents a confluence of the articular capsule, glenohumeral and coracohumeral ligaments, and the rotator cuff muscles.12-14

The coupled force vectors of the subscapularis and teres minor muscles contribute to depression of the humeral head in the glenoid cavity. This provides dynamic stability to the glenohumeral joint and prevents impingement of the humeral head with the acromion during deltoid activation. They also function to prevent superior translation of the humeral head after rotator cuff tear.15 Contrary to the rotator cuff tendons' ability to tolerate up to 100 N/mm of tensile strength, the tendons' endurance of compressive and shear forces is much less.16

The scapula also plays an important role in glenohumeral function by providing a stable base for muscle activation and load transfer within the kinetic chain. Alteration in normal scapular position or kinematics has been termed scapular dyskinesis and can affect rotator cuff function.17 Scapular dyskinesia has also been described following rotator cuff tears and is thought to represent a compensatory mechanism for glenohumeral motion deficits.18 Irritation and inflammation of the subacromial bursa, which is rich in nerve fibers, can also lead to pain inhibition of the rotator cuff.19

TENDON HEALING POTENTIAL

Though some partial-thickness and some small full thickness tears of the rotator cuff may heal spontaneously without surgical intervention, the natural history of rotator cuff injury appears to indicate that most small tears will enlarge if not surgically repaired.20 It remains unclear, however, over what time period this is likely to occur; but enlargement is typically associated with increased pain and dysfunction. Healing of ruptured rotator cuff tendons, therefore, only occurs when the tendon is surgically repaired back to its footprint on the proximal humerus.

Histological studies suggest that three phases of rotator cuff healing occur after surgical repair. These include an inflammatory phase, a proliferative or repair phase, and a remodeling phase.21 A firm understanding of the timing of these phases is important to safely individualize rehabilitation protocols after rotator cuff repair. Following surgical tendon-to-bone fixation, inflammatory cells followed by platelets and fibroblasts migrate into the repair site over the first week and begin to proliferate over the next 2–3 weeks. The cellular proliferation and matrix deposition of this phase is thought to be regulated by several growth factors and initially yields primarily type III collagen.22 Approximately three to four weeks following repair,
the remodeling phase begins and scar tissue organizes through extracellular matrix turnover. The initial type III collagen deposition is slowly replaced by type I collagen, continuing until mature scar tissue is formed.\textsuperscript{22} Remodeling repair tissue does not reach maximal tensile strength for a minimum of 12–16 weeks post repair.\textsuperscript{22,23} The normal tendon to bone transition including unmineralized and mineralized fibrocartilage is not recreated during the remodeling phase.\textsuperscript{22,24-25} Rather, repairing the rotator cuff to its anatomic location facilitates the formation of scar tissue in a manner that secures the torn tendon to the greater tuberosity in a more anatomic location. This, in turn, allows the rotator cuff to function at an anatomic length and tension, which is important if normal function is to be restored.

**SCIENTIFIC RATIONALE BEHIND POSTOPERATIVE TREATMENT MODALITIES**

Allowing healing of the repaired rotator cuff tendon while minimizing stiffness and muscle atrophy are the primary goals of postsurgical rehabilitation. Unfortunately, there is a paucity of high-level evidence in the literature to support or develop various postoperative rehabilitation protocols.\textsuperscript{26} Millett et al\textsuperscript{27} previously reported a widely used protective rehabilitation protocol based on available scientific evidence. Koo and Burkhart\textsuperscript{28} similarly presented both protective and accelerated rehabilitation protocols utilized based on individual patient risk for developing postoperative stiffness. The protective protocol, in which muscle strengthening exercises are delayed, is applied after arthroscopic repair of rotator cuff tears greater than 5 cm or involving more than 2 tendons, poor tissue quality, or repairs with greater tension.\textsuperscript{28} Each of these protocols implement various treatment modalities at different times to maximize healing and minimize stiffness based on repair characteristics such as tissue quality and repair robustness. The following sections report on the available evidence behind these various postoperative treatment modalities. A review of currently available literature on rehabilitation after rotator cuff tear repair on PUBMED / MEDLINE and EMBASE databases was performed.

**Immobilization**

Postoperative stiffness is reportedly the most common complication occurring after surgical repair of the rotator cuff, regardless of an arthroscopic or open technique, and is likely to occur with prolonged immobilization.\textsuperscript{28-32} Animal models, however, indicate that postoperative immobilization can minimize the tension on rotator cuff repairs and may lead to improved collagen orientation and visco-elastic properties as compared to immediate postoperative exercise treatment.\textsuperscript{33,34}

The optimal duration of immobilization following rotator cuff repair, therefore, continues to be controversial. Though some advocate early (passive) mobilization to reduce the rate of postoperative stiffness,\textsuperscript{29,33-36} a recent study suggests that longer immobilization periods, often recommended to protect surgical repairs, may not increase the incidence of post-operative stiffness.\textsuperscript{37} In addition, recent animal studies suggest that immobilization after rotator cuff repair of at least two weeks duration results in significantly less postoperative stiffness and increased active motion.\textsuperscript{38-39} The theory behind this assertion is that passive motion increases scar formation in the subacromial space resulting in decreased range of motion and increased stiffness.\textsuperscript{39}

The arm position during immobilization is also of importance during the early healing phase of the tendon repair. The use of an abduction immobilizer is currently widely used because of evidence suggesting that vascularization is improved and tension on the repaired tendon(s) is minimized in this position.\textsuperscript{40} Therefore, immobilization of the shoulder for 4–6 weeks in a slightly abducted position may minimize tension and maximize vascularization of the repair. The patient may come out of the immobilizer for supervised passive motion exercises in phase I of the rehabilitation, approximately week 1–4 postoperatively, and active assisted range of motion when commencing to phase II, usually week 4–6 postoperatively.

**Continuous Passive Motion (CPM)**

Continuous passive motion has been shown to minimize postoperative pain while maintaining range of motion following articular cartilage treatments and joint arthroplasty of the knee.\textsuperscript{41,42} The potential benefit after shoulder surgery, however, is less clear. Researchers performing several prospective controlled trials reported no significant difference in clinical outcome of a group of patients treated with CPM during the first 3–4 weeks following rotator cuff repair compared to a control group treated without
CPM. Additionally, Dockery et al found no difference in activity of rotator cuff muscles between mechanical CPM and manually-assisted CPM in an electromyographic study. Higher muscle activity was noted during patient self-assisted range of motion exercises as compared to mechanical CPM. To this end, CPM may be used to help maintain motion gains after glenohumeral manipulation while minimizing muscle activity; however its long term benefit is unclear and is otherwise not routinely prescribed.

Cryotherapy
Cryotherapy is used post-surgically to decrease pain, swelling, muscle spasm, and minimize the inflammatory response. Speer et al examined the use of cryotherapy in a prospective, randomized, controlled clinical trial that showed decreased pain and narcotic medication requirement during the first 24 postoperative hours. In addition, these patients had fewer pain complaints with therapy 10 days postoperatively and were better able to tolerate their rehabilitation. Others confirm these findings and report increased comfort and improved ability to sleep. Some evidence suggests that the use of pneumatic compression in conjunction with cryotherapy may enhance the effectiveness of both modalities. It is important to note, however, that high-quality, well-controlled studies examining the use of cryotherapy in conjunction with pneumatic compression do not exist. Based on this evidence the authors recommend the use of a home cryotherapy device for 10–14 days after surgery.

Joint mobilization
Joint mobilization techniques can be used to address joint stiffness and passive range of motion (PROM) deficits. Muraki et al demonstrated that glenohumeral distraction as well as anterior and posterior translational glides do not significantly alter stress on repaired supraspinatus tendons with the arm in resting position (30 degrees abduction in the scapular plane). In particular, posterior translational glides have shown to significantly increase external rotation range of motion in patients with stiff shoulders. These mobilizations are performed after positioning the extremity in the maximum available abduction and external rotation. The glides can be included in the early stages of rehabilitation at lower grades to assist in decreasing pain and guarding. Once the patient has progressed to 4–6 weeks after surgery, the mobilizations can be progressed to higher grades with the extremity positioned into maximum available abduction and external rotation.

Joint exercises and healing phases
Rehabilitation protocols are frequently divided into four phases; progressing from a maximum protection phase to a minimum protection phase. Within each phase, the patient experiences a gradual rotator cuff loading progression. Within each phase, the patient experiences a gradual rotator cuff loading progression based on studies detailing electromyography (EMG) activation of the rotator cuff during specific activities.

Activities resulting in minimal EMG activity begin in earlier phases when repair integrity and avoidance of stresses to the repair which could induce gapping is critical, whereas strengthening exercises that create higher EMG activity begin in later phases. By following this gradual progression of increasing EMG activity the authors facilitate protection of repair during the inflammation and proliferative phase when repaired tissue is immature and collagen reorganization in later phases once a threshold of stability is achieved. Pain, passive and active range of motion (ROM), and strength goals must be achieved within the present phase prior to initiating subsequent rehabilitation phases.

Some debate exists regarding early mobilization versus immobilization following arthroscopic rotator cuff repair. Denard et al performed a systematic review of articles related to postoperative stiffness following arthroscopic rotator cuff repair. They found stiffness to be more common in patients who were immobilized when compared to patients treated with an immediate passive range-of-motion protocol or a modified protocol that included early closed chain passive overhead stretching for patients who were in the at-risk group for post-operative stiffness. However, the authors suggest there may be a positive relationship between stiffness and rotator cuff healing with stiffness being considered a complication and recurrent rotator cuff tear a failure. Therefore the authors recommend a period of immobilization to encourage rotator cuff healing with modifications of rehabilitation protocols based on risk factors for post-operative stiffness that include:
(1) small tear size; (2) worker’s compensation; (3) age < 50; (4) calcific tendinitis; (5) adhesive capsulitis and, finally, (6) concomitant labral repair.

The following protocol incorporates gentle, partner-assisted, oscillatory passive range of motion to gradually increase patient range of motion while minimizing pain and stress to the repair. By avoiding any stretching into the end ranges of motion the authors believe that it is possible to avoid stressing the repair and limit any unnecessary increase in the inflammatory response. The patient is advanced to the next phase once the patient has achieved passive and active range of motion goals in addition to meeting the established time lines required for progression to next phase of rehabilitation.

PROPOSAL OF AN EVIDENCE-BASED APPROACH TO ROTATOR CUFF REHABILITATION

Postoperative rehabilitation following RC repair begins with close communication between the surgeon, his or her medical staff, and the physical therapy team. A review of surgical findings, such as the size of the tear, which tendons are involved, tissue quality, repair method, and concomitant procedures performed, is mandatory to establish rehabilitation guidelines. This communication continues throughout the recovery process and is an essential component in ensuring a successful outcome. Once the post-operative restrictions have been established, either a moderate (Appendix A) or conservative (Appendix B) rehabilitation protocol is selected and customized based on patient age, tear size, tissue quality, security of repair and additional procedures performed. Geriatric patients with large tears or poor tissue quality often require a conservative protocol, while younger patients with good tissue quality or a small tear would be appropriate for a moderate approach. Ultimately, the surgeon must communicate important findings so the course of treatment is appropriate for the patient.

The conservative protocol is characterized by either a delay in the initiation of and/or restriction of passive range of motion (PROM). It is common for PROM restrictions to last for 2–4 weeks. The aim is to minimize stress placed on the repaired tissues to facilitate early tissue healing. The moderate protocol is characterized by initiating PROM on postoperative day 1 while maintaining tolerable pain levels.

A home exercise program (HEP) should be incorporated into each phase of rehabilitation taking into account the post-operative restrictions that may apply. Initial HEP may include cervical, elbow, wrist, and hand AROM. A HEP should be provided regularly and individualized to address the observed impairments during periodic assessments throughout the phases.

Phase I

Regardless of the determined protocol, protection of the repaired tissue should be the focus of the initial phase of post-operative rotator cuff rehabilitation. However, there should be equilibrium between the promotion of tendon healing and preventing the development of postoperative adhesions. As previously mentioned, solid communication between surgeon and rehabilitation provider is mandatory. Depending on the integrity or location of the repair, certain passive motions (e.g. internal and external rotation, flexion, and abduction) may be restricted to protect sensitive repairs.

Directly following the repair the integrity of the repair relies mainly on the suture construct. Soon afterwards, collagen deposition and growth factors increase, with a peak increase around 10 days after surgery and a plateau phase is reached 28–56 days after the repair.22,25 The newly formed collagen network at this point still requires gentle stresses to positively affect fiber orientation however, the repair should not be exposed to the excessive forces imposed by active motion.

Within both the conservative and moderate treatment guidelines, passive range of motion of the glenohumeral joint begins as soon as it is deemed safe to minimize potential joint stiffness.29 Gentle joint oscillations in short-arm traction can be a useful technique to reduce muscle guarding and pain (Figure 1 A–D). PROM is progressed with caution, understanding that therapist-assisted passive motion (Figure 2) may be safer than other more active techniques due to the inherent increase in muscle activation present with other more active activities (i.e. use of pullies).43,55 Passive motion continues until symmetrical and pain free motion is achieved compared to the contralateral shoulder. In cases where the contralateral shoulder is symptomatic, PROM is continued until pain free motion is achieved that falls within established norms.56,57
Figure 1 A–D. Gentle joint oscillations in short-arm traction and various degrees of rotation with the arm in slight abduction.
When the shoulder is at rest, a neutral rotation sling is used throughout the first phase of rehabilitation. It is prudent during this phase to introduce prophylactic active motion of the elbow, wrist, hand, and cervical spine as well as postural education. Acute periscapular activation in the form of isolated scapular depression, protraction performed from a neutral position and back to neutral after each repetition, are appropriate and has shown to exhibit minimal posterior RC cuff activity (Figure 3 A–B). Scapular clock exercises and scapular retraction should be prescribed with discretion as these have been shown to increase EMG activity of the supraspinatus muscle to unsafe levels. Pendulum exercises can also be performed if done with small concentric circles of approximately 20 cm in diameter. This generates less than 15% of maximum voluntary isometric contraction activity in the supraspinatus and infraspinatus muscles.

Pendulum exercises can also be performed if done with small concentric circles of approximately 20 cm in diameter. This generates less than 15% of maximum voluntary isometric contraction activity in the supraspinatus and infraspinatus muscles.

The criteria to progress from phase I to phase II include: (1) passive forward flexion to at least 125 degrees; (2) passive external rotation in scapular plane to at least 75 degrees; (3) passive internal rotation in scapular plane to at least 75 degrees; (4) passive glenohumeral abduction to at least 90 degrees in the scapular plane.

**Phase II**

Phase two begins when the patient is cleared by the surgical team to begin active assisted range of motion (AAROM) followed by active range of motion (AROM). Rehabilitation criteria should include adequate PROM for advancement, minimal substitution patterns with PROM exercises (i.e. shoulder hiking with elevation) and minimal pain with PROM.

This phase typically commences 4–8 weeks after surgery, but may be delayed, depending on the age of the patient, comorbidities, and quality and size of the repair. From a histological perspective, the inflammatory and repair phases should have passed, and the healing progressed to the remodeling phase.

**Figure 2.** Therapist-assisted passive range of motion exercise of forward flexion.

**Figure 3 A–B.** Isolated scapular depression and protraction.
The application of low level forces during this time-frame aids in orienting the fibers within the collagen matrix and enhancing the tensile strength of the repair.\textsuperscript{22-23}

The authors suggest the use of AAROM during this timeframe, including supine glenohumeral external and internal rotation with a cane as well as supine flexion with the assistance of the uninvolved limb (Figure 4 A–B). An alternative AAROM technique is having the patient perform circles on a physioball placed on a table as the patient stands facing the ball with his hand and forearm resting on the ball. The authors believe this technique to incorporate most cardinal plane motions in one exercise. With the extremity supported on the ball, rotator cuff activity is likely diminished.

At this time, slow AROM exercises performed while submerged in neck deep water can also be a viable adjunct to land-based rehabilitation to improve glenohumeral joint range of motion.\textsuperscript{64} Active forward elevation performed in the scapular plane in a pool at 30° per second has shown to have less rotator cuff EMG activity, in terms of percent of maximal voluntary isometric contraction\textsuperscript{65}, than various land-based AAROM exercises performed in the same plane.\textsuperscript{66}

This offers patients a supported and safe environment to perform various active motions that will not place healing tissue in jeopardy.

Establishing proper neuromuscular control of the musculature of the shoulder girdle is essential to regaining full function following a rotator cuff repair. There is inherent risk in the post-operative shoulder for development of impaired scapulothoracic kinematics. If normal scapulothoracic kinematics are not restored, impingement syndrome may re-emerge.\textsuperscript{52,67}

Muscle force production and timing of contractions must be considered. The authors suggest using the prone position to help initiate proper muscle fiber activity patterns, particularly in the rhomboids and trapezius muscles. Scapular retraction/depression can help to deemphasize an often dominant upper trapezius muscle (Figure 5). The serratus anterior can be initially emphasized in the supine position with scapular protraction in 90 degrees of glenohumeral joint flexion, which is progressed to protraction at 120 degrees of flexion. Furthermore, the un-weighted bench press series serves as a good systematic progression to address active forward elevation and functional impairments; beginning in supine, then reclined and semi-reclined, and then upright sitting position as

\begin{figure}[h]
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\caption{Active-assisted range of motion exercises of internal rotation with the aid of a cane (A) and forward flexion with the help of the uninvolved limb (B).}
\end{figure}

\begin{figure}[h]
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\includegraphics[width=\textwidth]{figure5.png}
\caption{Stimulation of scapulothoracic musculature in the prone position.}
\end{figure}
Side lying external rotation, when performed properly, incorporates scapular stabilization with high infraspinatus and teres minor activity. Scapular plane elevation (scaption) with a flexed elbow, also known as “the salute exercise”, is an effective way to initiate recruitment of the supraspinatus muscle fibers (Figure 6 A–B). This exercise can be progressed to “the full can activity”, which is known to exhibit high supraspinatus muscle activity.

In addition, sub-maximal isometric external and internal rotation exercises and open-chain proprioceptive activities can be initiated at this time. These activities will gradually restore muscle strength and proprioception thereby establishing muscular balance. The exercises are performed with the arm below shoulder height, elbow flexed to approximately 90 degrees, held in a neutral rotation position with a towel roll placed between the elbow and trunk. The patient is asked to generate a force into internal rotation or external rotation, resisting with their uninvolved upper extremity, starting at approximately 25% of maximal effort and gradually increasing to 50–75% of maximal effort without reproducing pain. Open chain proprioceptive exercises are performed with the patient lying supine with the involved shoulder held in 90° of forward elevation (Figure 7). The patient is then instructed to draw circles and the alphabet in the air utilizing small, controlled motions. Also during this phase, any PROM, AROM, or soft tissue flexibility limitations must continue to be addressed as needed. To progress from phase II to phase III, the patient must have full active
range of motion as compared to the contralateral shoulder with no signs of scapular dyskinesia.

**Phase III**

Phase three is characterized by initial rotator cuff strengthening. This phase may begin when the patient demonstrates adequate passive and active glenohumeral range of motion, absent of substitution patterns, with acceptable scapulothoracic kinematics. The initiation of this phase is dependent on factors mentioned previously, such as tear size, tissue quality, and timing restrictions presented by the surgeon, as well as the clinical discretion of the therapist. Typically, this phase may begin between 8–12 weeks after surgery. At this point, tendon-to-bone healing should be able to endure the initiation of strengthening exercises. PROM and AROM exercises are continued if necessary, based upon therapist discretion.

During this phase, the patient progresses to isotonic and light closed chain stability exercises. The shoulder external and internal rotators are strengthened by performing said motions with the arm below shoulder height utilizing elastic resistance and with a towel roll placed between the arm and trunk to encourage proper technique, thereby minimizing substitution patterns. To initiate strengthening of the serratus anterior muscle, a bear hug exercise using elastic resistance is performed similar to the dynamic hug test described by Decker et al. The bear hug exercise is performed while standing with the back toward the wall, knees slightly bent, and the feet shoulder-width apart. The elbows are flexed to 45°, the arms are abducted 60° out from the trunk, and the shoulder is internally rotated to 45°. The patient then performs horizontal adduction of both upper extremities, following an imaginary arc at approximately 60 degrees of elevation until they obtain maximum scapular protraction by touching their fists together as to mimic a hugging motion around a cylindrical object (Figure 8 A–B). The patient then slowly returns to the starting position as described above.

The standing sport cord row exercise is used to strengthen the trapezius and rhomboid musculature (Figure 9), both important scapular stabilizers, in a fashion similar to the prone rowing type exercise that has been reported to elicit high levels of trapezius and rhomboid muscle activity in EMG studies.51,68

Figure 8 A–B. ‘Bear hug test’, horizontal adduction of both upper extremities in an axial plane, following an imaginary arc at approximately 60 degrees of elevation until maximum scapular protraction is obtained by touching fists together (B).
The prone lower trapezius exercise is similar to the prone full can exercise described by Ekstrom et al and was shown to elicit the greatest amount of EMG activity in the lower trapezius muscle.51

To address the biceps and triceps brachii muscles, conventional biceps curl and triceps extension exercises are used with either isotonic free weight resistance or elastic tubing (Figures 10 A–B and 11 A–B). Besides its role in forward flexion of the glenohumeral joint, the contribution of the long head of the biceps tendon to the stability of the glenohumeral joint (due to its' intra-articular insertion) is unclear and the results of in vitro studies and recent in vivo studies contradict.69,70 The triceps brachii acts as both a shoulder and elbow extensor and is active in closed-chain isotonic exercises like a chest press or in closed-chain stability exercises that are performed in the plank or quadraped positions.71

Initial closed chain stability exercises are started to improve neuromuscular control of the shoulder complex. Rhythmic stabilization in the quadruped position utilizing weight shifts and perturbations can be utilized to improve static control through compressive forces acting through the glenohumeral joint, which increase muscle activation and improve static stability of the shoulder complex.72 Once the patient is pain-free with activities of daily living and demonstrates ability to tolerate all phase III strengthening exercises without pain they can be progressed to phase IV.

Figure 9. The standing sport cord row exercise in order to strengthen the trapezius and rhomboid musculature.

The prone lower trapezius exercise is similar to the prone full can exercise described by Ekstrom et al and was shown to elicit the greatest amount of EMG activity in the lower trapezius muscle.51

Figure 10 A–B. Conventional biceps curl exercises with free weight resistance.
The advanced strengthening phase can typically be initiated approximately 12–16 weeks following rotator cuff repair. At this point, the remodeling phase is close to completion and the repaired rotator cuff tissue is relatively mature, therefore able to withstand greater stresses as compared with stresses encountered in earlier phases. The patient should be pain-free with activities of daily living and demonstrate the ability to tolerate all phase III strengthening exercises without pain or substitution. In addition, the patient should be able to perform active motions at multiple angles without signs of scapular dyskinesia. This phase is a progression of the previous phase and a transition to sport-specific rehabilitation activities and endurance of maximum tensile strength.22-23

Progressive strengthening of the posterior cuff muscles is accomplished in a standing position while performing external rotation of the shoulder at 45 degrees of abduction utilizing elastic resistance (Figure 12 A–B). This ensures high levels of infraspinatus and teres minor activation. By performing external rotation exercises at 90 degrees of abduction, supraspinatus muscle activity is optimally generated.67,73

The scapulothoracic articulation is also addressed using several exercises chosen to specifically target the scapular stabilizers. To further strengthen the serratus anterior muscle, a punch with a plus exercise utilizing elastic resistance is performed. This exercise combines the bench press and the supine scapular protraction exercises used for AROM in phase II that have shown to elicit high EMG activity of the serratus anterior muscle. This exercise is performed standing, facing away from the elastic resistance attachment with the hands held at shoulder width and chest height, holding onto the resistance band or cord. The upper extremities are then extended forward away from the body similar to a bench press motion at approximately 120 degrees of forward elevation followed by protraction of the scapula.50-51 Additionally, the push-up with a plus progression is a more advanced exercise that strengthens the serratus anterior muscle (Figure 13).50 It gradually increases gravity resistance and begins with pressing against a wall, progressing to the edge of a table, and finally to the floor.

Advanced rhythmic stabilization training is instituted having the patient stabilize their upper extremity in a position of 90° of external rotation and 90° of forward elevation in the scapular plane (“statue of liberty position”). Once in this position the patient is challenged to maintain this position against elastic resistance while performing rapid oscillations with a rubber bar (Figure 14). This exercise can be modified by rotating around the patient, altering the direction of pull, as they perform the exercise. Additionally, advanced closed chain stability exercises are performed in the quadruped position while stepping on and off steps of various heights and angles. Manual resisted proprioceptive neuromuscular facilitation through diagonal resistance exercises can be implemented at this time to continue the progression of rhythmic stabilization with the added benefit of the physical therapist being able to apply varying amounts of resistance in multiple planes of movement.

Finally, plyometrics for the upper extremity may be initiated towards the end of this phase to train the...
Figure 12 A–B. Strengthening of the posterior rotator cuff by performing external rotation against elastic resistance with the arm in 45° of abduction.

Figure 13. The push-up plus progression exercise.

Figure 14. The ‘Statue of Liberty’ exercise.
shoulder and upper extremity musculature to dissipate forces similar to what would be encountered once the patient returns to sport. Typically the patient will start by performing bilateral throws and progress to unilateral throws against a wall, rebounder, or by involving a partner using progressively heavier weighted balls. These exercises should start at positions at or near shoulder height progressing to the overhead position (Figure 15 A–B). Due to the aggressive nature of these exercises, collaborating with the orthopedic team to evaluate the appropriateness of these exercises is necessary. The patient's age, the sport he or she is returning to, and the integrity and size of the cuff repair should all be carefully considered before implementing these exercises into a plan of care.

Return to sport
A gradual, progressive return to sport rehabilitation plan is initiated after completing phase IV and prior to returning to competitive sporting activities. The interval sports program should begin only after the patient has been cleared by the surgeon and has achieved symmetric motion and strength, normalized scapulothoracic kinematics, and has no complaints of pain at rest or with activities.

Sports specific training exercises should only be commenced when the patient is fully rested and after a 5–10 minute cardiovascular warm-up. The program should be performed three times per week with at least one rest day in-between sessions. To advance to the next level the patient must be able to complete the prior level without pain or limitations. A maintenance exercise program focusing on cardiovascular endurance and flexibility along with scapulothoracic, rotator cuff, lower extremity, and core strength should be performed on alternate days.

An interval golf program is an example of a return to sport program that should be completed prior to returning to full, unrestricted golf play. The program is initiated with putting and chipping and gradually works through short, medium, and long distance irons and woods. Once the patient is able to work through all clubs and equal the approximate number of strokes expected in 9-holes of golf without pain or
soreness, then they can play 9-holes of golf on a course. If they can successfully complete 3 rounds of 9-holes without pain or soreness they may then progress to playing 18-holes.74

An interval tennis program is another example of a return to sport program that should be utilized prior to returning to full, unrestricted tennis play. The program for tennis players progresses from limited number of forehand and backhand ground strokes progressing to overhead serves and culminating in a return to competitive matches occurring over a 4 week period.75

CONCLUSIONS
This review describes a rotator cuff rehabilitation protocol that incorporates currently available scientific literature guiding rehabilitation. To this end, expert experience remains a large facet of rehabilitation protocols.

Postoperative rehabilitation following RC repair begins with close communication between the surgeon, his or her medical staff, the patient, and the physical therapy team. A review of surgical findings is mandatory to establish rehabilitation guidelines. This communication continues throughout the recovery process and is an essential component in ensuring a successful outcome. Once the post-operative restrictions have been established, either a conservative or moderate rehabilitation protocol is selected and customized based on surgical findings. The conservative protocol is characterized by either a delay in the initiation of and/or restriction of passive range of motion. It is common for restrictions to last for 2–4 weeks. The aim is to minimize stress placed on the repaired tissues to facilitate early tissue healing. The moderate protocol is characterized by initiating passive range of motion on postoperative day 1 while maintaining tolerable pain levels.

LIMITATIONS AND FUTURE RESEARCH
Rehabilitation protocols have traditionally varied considerably between providers with respect to timing of progression and appropriate therapeutic exercise. Rehabilitation protocols are frequently based on clinical experience and expert opinion rather than scientific rationale. Future research could be focused on more detailed timing and quality of progression through rehabilitation.

REFERENCES


64. Brady, B., Redfern, J., MacDougall, G., et al. The addition of aquatic therapy to rehabilitation following surgical rotator cuff repair: a feasibility
Appendix A. Moderate rehabilitation protocol following arthroscopic rotator cuff repair.

### Arthroscopic Rotator Cuff Repair - Moderate Rehabilitation

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- Do exercise for that week/month

#### Phase I - Maximal Protection

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- Begin full AROM: 5-6 weeks

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- T.E.D. Hose 2 weeks to prevent DVT

| Sidelying External Rotation | ● | ● | ● | ● | ● | ● | ● | ● | ● |    |    |    |    |    |
| Forward Elevation & Scaption | ● | ● | ● | ● | ● | ● | ● | ● | ● |    |    |    |    |    |
| Prone Horizontal Abduction w/ ER | ● | ● | ● | ● | ● | ● | ● | ● | ● |    |    |    |    |    |
| Prone Lower Traps to 60 | ● | ● | ● | ● | ● | ● | ● | ● | ● |    |    |    |    |    |
| Prone Extensions with ER | ● | ● | ● | ● | ● | ● | ● | ● | ● |    |    |    |    |    |
| Open Chain Proprioception | ● | ● | ● | ● | ● | ● | ● | ● | ● |    |    |    |    |    |

#### Low Load Prolonged Stretches

| Door Jam Series | ● | ● | ● | ● | ● | ● | ● | ● | ● |    |    |    |    |    |
| Towel Internal Rotation | ● | ● | ● | ● | ● | ● | ● | ● | ● |    |    |    |    |    |
| Cross Arm Stretch | ● | ● | ● | ● | ● | ● | ● | ● | ● |    |    |    |    |    |
| Sleeper Stretch | ● | ● | ● | ● | ● | ● | ● | ● | ● |    |    |    |    |    |
| TV Watching Stretch | ● | ● | ● | ● | ● | ● | ● | ● | ● |    |    |    |    |    |
| 90/90 External Rotation Stretch | ● | ● | ● | ● | ● | ● | ● | ● | ● |    |    |    |    |    |

#### Activities of Daily Living (ADL’s)

| Eating/Drinking (Elbow motion ok) | ● | ● | ● | ● | ● | ● | ● | ● | ● |    |    |    |    |    |
| Dressing                         | ● | ● | ● | ● | ● | ● | ● | ● | ● |    |    |    |    |    |
| Washing/Showering                | ● | ● | ● | ● | ● | ● | ● | ● | ● |    |    |    |    |    |
| Computer with supported arm     | ● | ● | ● | ● | ● | ● | ● | ● | ● |    |    |    |    |    |
| Driving                          | ● | ● | ● | ● | ● | ● | ● | ● | ● |    |    |    |    |    |
| Lifting up to 5 lbs.             | ● | ● | ● | ● | ● | ● | ● | ● | ● |    |    |    |    |    |
| Overhead Activity                | ● | ● | ● | ● | ● | ● | ● | ● | ● |    |    |    |    |    |
| Lifting greater than 5 lbs.      | ● | ● | ● | ● | ● | ● | ● | ● | ● |    |    |    |    |    |

The intent of this protocol is to provide guidelines for progression of rehab. It is by no means intended to serve as a substitute for clinical decision making. Progression through each phase of rehab is based on clinical criteria and time frames as appropriate. It is important that each phase of rehab is mastered prior to initiating the next phase to insure proper healing of repaired tissues.
| Phase III: Initial Resistance Strengthening & Proprioception | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 13 | 17 | 21 | 25 |
|------------------------------------------------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|    |
| External Rotation                                          | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |
| Internal Rotation                                          | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |
| Punches with a Plus                                        | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |
| Sport Cord Rows                                            | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |
| Prone Lower Trap                                           | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |
| Bicep Curls                                                | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |
| Triceps Extensions                                         | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |
| Initial Push-up Plus                                       | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |
| Initial Closed Chain Stability                             | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |

| Phase IV: Advanced Resistance Strengthening & Proprioception | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 13 | 17 | 21 | 25 |
|--------------------------------------------------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|    |
| External Rotation at 45º                                      | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |
| Bear Hugs                                                    | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |
| External Rotation at 90º                                     | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |
| Statue of Liberty                                            | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |
| Advanced Push-up Plus                                       | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |
| Advanced Closed Chain Stability                             | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |
| PNF with Resistance                                         | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |
| Decelerations                                               | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |
| Plyometric External Rotation                                | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |

| Phase IV: Weight Lifting in Gym and Return to Sports | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 13 | 17 | 21 | 25 |
|-----------------------------------------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|    |
| Skiing                                               | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |
| Throwing Progress                                    | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |
| Overhead and Serving Sports                          | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |
| Contact Sports                                       | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |
| Swimming                                              | ● | ● | ● | ● | ● | ● | ● | ● | ● | ●  | ●  | ●  |    |    |

**CRITERIA:** FULL PAIN FREE, MOTION AND FULL ROTATOR CUFF STRENGTH RESTORED NO LAT PULLS BEHIND BACK, OR WIDE GRIP BENCH PRESS

Therapist: 

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The International Journal of Sports Physical Therapy | Volume 7, Number 2 | April 2012 | Page 216
Appendix B. Conservative rehabilitation protocol following arthroscopic rotator cuff repair.

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<tr>
<th>Arthroscopic Rotator Cuff Repair - Conservative Rehabilitation</th>
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<td>Name: ____________________________  DOS: __________________</td>
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<td>Dr: ______________________________ DX: ____________________</td>
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- Do exercise for that week

### Phase I – Maximal Protection Passive Range of Motion (PROM)

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### Phase II – Minimal Protection Active Range of Motion (AROM)

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<td>Internal &amp; External Rotation</td>
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<tr>
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### T.E.D. Hose

- 2 weeks to prevent DVT’s

### Time Lines

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<td>Forward Elevation &amp; Scaption</td>
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</table>

### Low Load Prolonged Stretches

- Door Jam Series | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
- Towel Internal Rotation | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
- Cross Arm Stretch | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |

### Activities of Daily Living (ADL’s)

- Eating/Drinking (Elbow motion ok) | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
- Dressing | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
- Washing/Showering | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
- Computer with supported arm | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |

The intent of this protocol is to provide guidelines for progression of rehab. It is by no means intended to serve as a substitute for clinical decision making. Progression through each phase of rehab is based on clinical criteria and time frames as appropriate. It is important that each phase of rehab is mastered prior to initiating the next phase to insure proper healing of repaired tissues.
### Phase III: Initial Resistance

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### Phase IV: Advanced Resistance

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### Phase IV: Weight Lifting in Gym and Return to Sports

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**CRITERIA:** FULL PAINFREE MOTION AND FULL ROTATOR CUFF STRENGTH RESTORED

NO LAT PULLS BEHIND BACK, OR WIDE GRIP BENCH PRESS

Check with MD

Therapist:
ABSTRACT

Individuals with midfoot injuries may present to physical therapists in a variety of clinical settings. The ability of the physical therapy practitioner to optimally manage the care of such an individual may be dependent on understanding the diagnostic imaging that is indicated or has been completed. Among the potentially most debilitating midfoot injuries are Lisfranc fracture-dislocations. This case outlines the use of conventional radiology, standard computerized tomography (CT), and three-dimensional CT for differential diagnosis of Lisfranc and associated midfoot injury in a 26 year-old female recreational athlete. Her subsequent surgical and post-surgical management is briefly discussed.

Physical therapists evaluating patients with suspected midfoot injuries should be cognizant of the tendency for Lisfranc injuries to escape initial detection, possibly precipitating misdiagnosis or delay to diagnosis. Non-weight-bearing radiography may be insensitive to demonstrating the anatomical disruption of significant midfoot injuries. Weight-bearing radiographic views along with selective use of MRI and CT aid in proper identification of injury to the tarsometatarsal joints and optimal management of patients with these injuries.

Key words: diagnostic imaging, Lisfranc injury, midfoot injury

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INTRODUCTION

Individuals with midfoot injuries may present to physical therapists in a variety of clinical settings. The ability of the physical therapy practitioner to optimally manage the care of such an individual may be dependent on understanding the diagnostic imaging that is indicated or has been completed. Among the potentially most debilitating midfoot injuries are Lisfranc fracture-dislocations. Lisfranc fracture-dislocations are an uncommon, but serious injury occurring as a result of trauma to the tarsometatarsal articulations of the midfoot.\(^1,2\) The historical basis for the eponym has been described as originating with French surgeon Jacques Lisfranc de St. Martin. Lisfranc reported on midfoot injuries when calvarymen would fall from their horses with a foot remaining plantar flexed in the stirrup during Napoleon Bonaparte’s military campaigns.\(^3\) Similarly, Lisfranc also described the midfoot amputation he pioneered.\(^4,5\)

In present day athletes, midfoot injuries, including Lisfranc fracture-dislocations, have been observed to occur from forced plantar flexion or abduction of the forefoot in open and closed chain conditions.\(^4,5\) Another causative circumstance can occur with an axial force driven downward through the calcaneus while the foot is plantarflexed.\(^3,6\) Other high impact trauma events, as has been reported in motor vehicle accidents or in industrial settings, can result in direct crushing type injuries to the tarsometatarsal joints\(^2,7\) and numerous other mechanisms exist in sport specific situations.\(^6\)

Clinical Presentation

The patient in this case report was a 26 year-old female, who regularly participated in a recreational indoor soccer league and also ran competitively, including marathon events. During a soccer game, she was kicked by another athlete directly on the bottom of her soccer shoe with the immediate onset of severe foot pain and a subsequent inability to weight-bear. The athlete, who is a physical therapist, described the transverse and longitudinal arches of her foot collapsing.

She received emergent evaluation and care, including radiography of her injured foot. In her case, radiography revealed significant osseoligamentous injury of her foot. The standard radiologic examination was supplemented by standard computed tomography (CT) and three-dimensional CT because of the need for further description of the pathology and surgical planning. The accompanying images reveal multiple fractures along the tarsometatarsal joints along with suggestions of ligamentous instability (Figures 1-8).

Evaluation and Diagnostic Imaging

The American College of Radiology Appropriateness Criteria\(^8\) for the patient with traumatic foot injury incorporates the predictors of the Ottawa Ankle and Foot Rules, suggesting the most contributory imaging for best decision making toward management of the patient’s care. The Ottawa Rules suggest standard three-view radiography of foot if there is tenderness to palpation of the navicular or fifth metatarsal or if the patient has an inability to weight-bear.

The clinical suspicion of a Lisfranc injury, however, can influence the imaging modality selection and
methodology. Under Variant 1, in which the Ottawa Rules are met, the initial studies recommended are radiographs. Under Variant 4, with clinical suspicion of significant midfoot injury, radiography is recommended and with weight-bearing views, even if the patient is negative on the Ottawa Rules. Weight-bearing views have been shown to increase the abnormal alignment at the first intermetatarsal space, thus making the identification of a Lisfranc injury easier.

Most frequently, nonweight-bearing three-view radiographs are the initial imaging studies performed in the case of traumatic foot injury. Fractures and malalignments may be adequately demonstrated on standard anterior-posterior (A-P), internal oblique, and lateral view nonweight-bearing radiography, as occurred in this case (Figures 1-4). Lisfranc injuries, however, often have subtle findings which may escape initial radiographic assessment. The absence of weight-bearing views can lower the diagnostic accuracy of radiography.

The lack of valid radiographic results or their misinterpretation are likely contributors to the mismanagement of those with Lisfranc injuries. Multiple studies cite initial misdiagnosis or delay to diagnosis occurring in 20-40% of Lisfranc injuries.

Clinical examination findings that particularly elevate the suspicion for Lisfranc injury include a

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Figure 2. Enlargement of the Tarsometatarsal Joints. Note the fractures and malalignment at the bases of the second through fourth metatarsals and the increased space between the medial and intermediate cuneiforms.

Figure 3. Oblique Radiograph of the Foot. Note the fractures across the second through fourth metatarsal bases, indicated within the circle.

Figure 4. Enlargement of the Oblique View. The fractures are more clearly demonstrated in this enlarged image.
grossly edematous foot in which passive abduction and pronation are particularly provocative of foot pain. Additionally, the presence of ecchymosis on the plantar aspect of the foot has been reported to be an indicator of significant midfoot injury. Myerson et al. report a clinical stress test consisting of squeezing the first and second metatarsal interspace in the coronal plane to stress the base of the middle and the medial column in an attempt to elicit pain or a palpable click. This clinical exam procedure, however, has yet to be standardized and validated. To further enhance radiographic detection, stress views of the foot with passively applied pronation and abduction in combination has been suggested. This procedure, also, has yet to be validated and is not yet incorporated into the American College of Radiology Appropriateness Criteria.

In the case of persistent clinical suspicion of a Lisfranc injury, even in the presence of normal radiographs or indeterminate study interpretations, or if the patient is intolerant of weight-bearing radiographs, MRI and/or CT are indicated as the next imaging studies. Both studies may be warranted, given the potential for structural compromise of the bony elements and the ligaments spanning the joints. The superior capacity of MRI to depict the ligamentous tissues allows for excellent detection of midfoot injury, including those radiographically occult lesions. CT may also be
used because of its excellent ability to detect disrup-
tion of cortical bone.4,5 In the case of this particular
patient, standard CT and three-dimensional CT images
allowed for further appreciation of the detail of the
fractures and malalignment across the tarsometatarsal
joints, most notably between the intermediate and lat-
eral cuneiforms, cuboid, and the second through
fourth metatarsals (Figures 5-8).

Management Process
The patient immediately underwent open reduction
internal fixation with percutaneous pinning to restore
anatomical alignment and stabilize the tarsometatar-
sal joints. Her foot was immobilized post-operatively
and her ambulatory status was designated as non-
weight-bearing for 12 weeks. The extent of weight-
bearing restriction is typically a function of the severity
of the injury and the complexity of the reconstructive
procedure with six weeks of nonweight-bearing being
common.2,16 The return to weight-bearing is typically
based on additional radiographic evidence of fracture
healing.4 Physical therapy interventions during the
maximum protection phase included screening for
venous thromboembolism, management of pain and
edema, and gait training with crutches and a Roll-A-
Bout™. She also completed an exercise program
directed at maintaining the hip and knee muscula-
ture of the affected lower extremity.

After the maximum protection phase, physical ther-
apy interventions were aimed at restoring mobility
and strength in the lower limb. This included man-
ual mobilization of the talocural and substalar joints.
The patient was able to progress from wearing a cam
walking boot to athletic shoes with routine ambula-
tory activity. Shoes providing minimal support were
generally avoided because of reports of pain when
walking. Pain continued to be a limiting factor dur-
ing her rehabilitation progression from the elliptical
exercise device and bicycle to running on a tread-
mill. This was addressed with semi-rigid custom-fit
orthotics, which resulted in an increased tolerance
to running. Her conditioning toward returning to
recreational running was enhanced by running in a
swimming pool and transitioning to a treadmill. She
specifically avoided cutting activities or running on
grass or sand because return to these activities is
usually deferred until late in the rehabilitation pro-
cess, typically four months after surgical repair.2,4

Although not a factor in this patient, complications
have been reported to occur in patients having Lis-
franc injuries. Most notable in the immediate post-

Figure 7. Enlargement of the Three-Dimensional CT
Image of the Tarsometatarsal Joints. Further detail is
revealed of the fractures of the second through fourth metatarsal bases.

Figure 8. A Conventional CT Coronal Reconstruction
through the Tarsometatarsal Region. The fracture lines are
clearly delineated and the extent of displacement of the
fracture fragments is revealed in this image.
Practitioners must be vigilant to recognize any indication of neurovascular compromise due to the potentially catastrophic consequences that might occur if not appropriately treated. Later occurring complications include malunion, nerve irritation, and complex regional pain syndrome. A frequent long-term result, particularly in those undergoing open reduction and internal fixation of Lisfranc injuries, is post-traumatic arthrosis. In such cases, primary arthrodesis is often chosen to maximize functional mobility.

Outcomes

Customarily, athletes that undergo surgical fixation of a Lisfranc fracture-dislocation should expect to be sidelined for 12 to 16 weeks. Often, return to sport is based on the symptoms of the individual and the sport to which the athlete is attempting to return. For higher impact sports and those requiring rapid directional changes, this particular injury may be career ending for the athlete.

At the 16 week reassessment, the patient continued to demonstrate limitations in strength and mobility of her foot and ankle. Although motivated to begin running again, she continued to have pain with higher impact weight bearing activities. Her daily level of pain was largely dependent on her level of activity and footwear. She reported pain levels of four of 10 on a numerical pain scale at the end of her workday in unsupportive shoes, but only one of 10 when wearing athletic shoes. Her greatest level of pain during the rehabilitative phase was rated at seven of 10, subsequent to wearing high-heeled shoes.

Approaching the six month mark after injury, her strength and range of motion were approaching that of her uninvolved side. Her activity tolerance, including running, accelerated after initiating the wear of the custom-fit orthotic devices. She returned to running outdoors and completed a half marathon approximately six months after the injury.

Recommendation

Physical therapists evaluating patients with suspected midfoot injuries should be cognizant of the tendency for Lisfranc injuries to escape initial detection, possibly precipitating misdiagnosis or delay to diagnosis. Non-weight-bearing radiography may be insensitive to demonstrating the anatomical disruption of significant midfoot injuries. Weight-bearing radiographic views along with selective use of MRI and CT aid in proper identification of injury to the tarsometatarsal joints and optimal management of patient care. Those patients who demonstrate plantar ecchymosis, have pain provoked with passive foot abduction or pronation, or have pain elicited with manual approximation of the first and second metatarsals in the coronal plane warrant particular suspicion for Lisfranc injury and may need additional imaging for complete diagnosis.

REFERENCES


ABSTRACT

Background and Purpose: While the popularity of instability resistance training (resistance training that involves the use of unstable surfaces and devices: IRT) is evident in fitness training facilities, its effectiveness for optimal sport performance training has been questioned. The purpose of this clinical commentary is to explore the resistance training literature, which implements the use of unstable surfaces and devices to determine the suitability of IRT for rehabilitation.

Description of Topic and Related Evidence: The criticism of IRT for athletic conditioning is based on the findings of impaired kinetic measures such as force, power and movement velocity during a bout of IRT compared to traditional resistance training with more stable surfaces or devices. However, these deficits occur concurrently with minimal changes or in some cases increases in trunk and limb muscle activation. Compared to the kinetic deficits that are reported during unstable resistance exercises, the relatively greater trunk muscle activation indicates a greater stabilizing function for the muscles. IRT exercises can also provide training adaptations for coordination and other motor control issues, which may be more important for low back pain rehabilitation than strength or power enhancements.

Relation to Clinical Practice: Improvements in postural stability from balance training without resistance can improve force output which can then lead to a training progression involving an amalgamation of balance and IRT leading to higher load traditional resistance training.

Key words: low back pain, injuries, strength training, balance, injury recovery, injury prevention
BACKGROUND AND PURPOSE
Instability resistance training (IRT) devices are very popular in current training facilities. IRT involves resistance exercises either with body mass as a resistance or external loads (e.g. dumbbells, barbells) that are performed on an unstable surface or using unstable devices. It would be difficult to find a fitness facility without some sort of instability device such as Swiss balls, BOSU® balls (definition: BOth Sides Up, description; a hemispherical inflated ball that is flat on one side and convex on the other), foam rollers, wobble boards, suspended chains, ropes, or other devices. Interestingly, Swiss balls which derived their name from Swiss physical therapists, who were purportedly the first to incorporate these balls (prior to World War II) are not called Swiss balls by Swiss physical therapists. The Swiss use the term physioballs, while the Germans call them pezzi balls. No matter what these balls are labeled, balls and other instability devices presently permeate the fitness and rehabilitation environment. However popularity is not always equated with effectiveness. The Canadian Society for Exercise Physiology (CSEP) position stand1 on the use of instability to train the core or trunk musculature does not fully endorse instability training for athletic or sport performance training. They state, “ground based free weights are highly recommended for athletic conditioning of the core musculature as they can provide the moderately unstable environments to augment core and limb muscle activation while still providing maximal or near maximal force and power outputs".1, p. 111 However, they balance that statement by indicating, “Individuals who are involved with rehabilitation, health-related fitness pursuits or cannot access or are less interested in the training stresses associated with ground based free weight lifts, can also receive beneficial resistance training (RT) adaptations with instability devices and exercises to achieve functional health benefits". 1, p. 111 Thus it is necessary to examine the literature to determine why such delineation is recommended between trained, health enthusiasts and the previously injured recovering population.

The purpose of this clinical commentary is to investigate the resistance training literature that examines the utilization of unstable surfaces and devices when performing resistance exercises either with body mass (callisthenic exercises) or with external loads (e.g. barbells and dumbbells) to determine the role of IRT for rehabilitation. Much of the literature has investigated the acute and chronic responses to instability training with healthy, young individuals. Thus, the second purpose of this commentary is to apply these findings regarding the use of IRT to injury prevention and rehabilitation.

EFFECT OF IRT ON FUNCTIONAL PERFORMANCE AND MUSCLE ACTIVATION
The primary basis for the CSEP position stand's advocacy of traditional ground based free weights (e.g. squats, dead lifts, Olympic lifts) over IRT (performing resistance exercises either on an unstable platform or using an unstable implement) for athletes is associated with the predominant literature that demonstrates significant force reductions when performing force or power actions under unstable versus stable conditions. Table 1 illustrates from a sample of instability studies that investigate force or power output during exercises performed under unstable conditions compared to the same exercises performed under stable conditions. Force or power, on average, decreases 29.3% with an effect size2 of 2.1 indicating a large magnitude of change. As an example, to highlight particular studies, the performance of resistance exercises while sitting or lying on a physioball resulted in decreased force output during leg extension (↓70%)3, plantar flexion (↓20%)3, and isometric chest press (↓60%).4 Whereas isometric force tends to be reduced, 1RM isokinetic bench press strength on a physioball compared to a stable bench press was maintained.5 Koshida et al7 suggested that the statistically significant yet minor deficits in force, power and velocity (6-10%) with a dynamic bench press performed on a physioball may not compromise the training response. Since, Koshida and colleagues7 used 50% of 1 RM, the possible training effects may be more applicable to power and endurance rather than maximal and hypertrophic strength training. In addition to instability-induced force and power deficits, instability exercises have been shown to adversely affect movement velocity and range of motion when performing a squat.8 Hence the ability to exert force, power or move at high velocity is strongly related to an indi-
individual's balance and stability when performing the task. For example, Behm et al.\(^9\) reported a significant correlation of 0.65 between a static balance measure (number of contacts with the floor while balancing on a wobble board) and maximum skating speed with young hockey players. In other words, if an individual can improve their balance and stability then strength and power may increase as well.

Adhering to the concept of training specificity,\(^{10}\) balance only training studies (without resistance) have generally been very successful at improving measures of balance and proprioception. Table 2 demonstrates from a sample of balance only training studies (without resistance) that balance and proprioception measures improved by 105% with an effect size of 1.2 indicating a large magnitude of change. Improvements in balance and proprioception not only provide positive benefits for reducing the incidence of accidents such as falls but also improve functional performance measures such as strength, power, running, and other activities. Table 3 results demonstrate that balance training alone with no strength, power, or functional training on average improved measures of functional performance by 31% with an effect size of 0.58 indicating a moderate magnitude of change. Thus, just by improving balance or postural stability without concomitant RT, functional performance can be enhanced. These findings are of particular importance to the field of rehabilitation when musculoskeletal injuries such as ankle sprains can impede balance and impact functional performance. Furthermore, it is common that early in the rehabilitation process force and power production can be hampered by inflammation, pain, and stiffness and thus a balance only training program may be an important initial phase to ameliorate an individual's strength and power. A balance-training program is a safe and productive first step in the rehabilitation plan, which can then be followed by progressive levels of resistance on unstable surfaces or with unstable devices (IRT).

The question would arise as to whether the subsequent step would be to implement separate balance

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<th>Authors(s)/Year</th>
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<th>Intervention</th>
<th>% change</th>
<th>Effect Size</th>
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<tr>
<td>Kornecki and Zschorlich 1994(^{26})</td>
<td>12</td>
<td>Pushing action with varying degrees of freedom (force)</td>
<td>-20%</td>
<td>1.93</td>
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<td>Behm et al. 2002(^{22})</td>
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<td>Pushing action with varying degrees of freedom (power)</td>
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<td>Behm et al. 2002(^{22})</td>
<td>8</td>
<td>Leg extension MVC force under stable versus unstable conditions</td>
<td>-70.50%</td>
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<tr>
<td>Anderson and Behm 2004(^{17})</td>
<td>10</td>
<td>Plantar flexion MVC force under stable versus unstable conditions</td>
<td>-20.20%</td>
<td>1.6</td>
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<td>McBride et al. 2006(^{28})</td>
<td>9</td>
<td>Bench press under stable versus unstable conditions</td>
<td>-59.60%</td>
<td>5.2</td>
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<td>Sparkes and Behm 2010(^{15})</td>
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<td>Isometric squat peak force output in stable vs. unstable conditions</td>
<td>-83.80%</td>
<td>2.48</td>
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<td>Drinkwater et al. 2007(^{7})</td>
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<td>MVC squat force output in stable vs. unstable</td>
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<td>Cowley et al. 2007(^{30})</td>
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<td>Squat power under stable and unstable conditions</td>
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<td>Cowley et al. 2007(^{30})</td>
<td>14</td>
<td>Squat concentric force under stable and unstable conditions</td>
<td>-24%</td>
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<td>Koshida et al. 2008(^{106})</td>
<td>20</td>
<td>Work capacity of barbell chest press on stable versus unstable ball pre-training</td>
<td>-12%</td>
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<td>Goodman et al. 2008(^{105})</td>
<td>13</td>
<td>Strength of barbell chest press on stable versus unstable ball pre-training</td>
<td>-3.70%</td>
<td>0.01</td>
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<td>Kishida et al. 2008(^{106})</td>
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<td>Strength of barbell press on stable versus unstable ball post-training</td>
<td>2%</td>
<td>0.5</td>
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<tr>
<td>Goodman et al. 2008(^{105})</td>
<td>13</td>
<td>Force during dynamic bench press under stable vs. unstable conditions</td>
<td>0.70%</td>
<td>0.16</td>
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<tr>
<td>Kohler et al. 2010(^{102})</td>
<td>30</td>
<td>Velocity during dynamic bench press under stable vs. unstable conditions</td>
<td>-12.50%</td>
<td>0.61</td>
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<td>Chulvi-Medrano et al. 2010(^{103})</td>
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<td>Bench press 1 RM strength under stable versus unstable conditions</td>
<td>-1.50%</td>
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<td>Total</td>
<td>179</td>
<td>Mean</td>
<td>-29.3%</td>
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and stable RT exercises programs or to attempt to incorporate both balance (stability) and resistance into the same exercises (IRT). Based on the predominant instability-induced decreases in force, power and velocity (Table 1) when compared to traditional stable RT exercises, it has been suggested that trained athletes need a greater adaptive stimuli (force, velocity, and rate of force production)\textsuperscript{11,12} which may not achieve the training threshold when performed on unstable devices.\textsuperscript{13} However, a number of IRT studies have reported substantial training gains that in some cases were comparable to those achieved with traditional stable RT programs. Table 4 demonstrates that IRT programs achieved on average 22% gains in functional performance measures with an effect size of 0.98 indicating a large magnitude of change with 4-10 weeks of training. For example, untrained individuals involved in seven\textsuperscript{14} or eight weeks\textsuperscript{15} of either traditional stable

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Table 2. Sample of Studies Examining the Effect of Balance Training on Balance and Stability.

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<td>Tsang et al. 2003\textsuperscript{84}</td>
<td>42</td>
<td>Comparison of static standing and limits of stability tests for maximum excursion between elderly control and Tai Chi subjects</td>
<td>13%</td>
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<td>Stanton et al. 2004\textsuperscript{104}</td>
<td>18</td>
<td>Swill ball training (6 weeks) on Sarhmann test of core stability</td>
<td>450%</td>
<td>2.88</td>
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<td>Bruhn et al. 2004\textsuperscript{105}</td>
<td>33</td>
<td>Sensorimotor training on postural stabilisation</td>
<td>6.8%</td>
<td>0.1</td>
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<tr>
<td>Li et al. 2004\textsuperscript{106}</td>
<td>188</td>
<td>Functional balance measures on the Berg balance scale with 12 month study period</td>
<td>7.90%</td>
<td>-</td>
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<tr>
<td>Giofisidou et al. 2006\textsuperscript{107}</td>
<td>13</td>
<td>Balance training (12 weeks) on Instability index</td>
<td>51%</td>
<td>1.11</td>
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<td>Kean et al. 2006\textsuperscript{108}</td>
<td>24</td>
<td>Static balance time with fixed foot balance training</td>
<td>9.50%</td>
<td>0.57</td>
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<td>Yaggie et al. 2006\textsuperscript{109}</td>
<td>36</td>
<td>Balance training effects on balance</td>
<td>68.5%</td>
<td>1.43</td>
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<tr>
<td>Nagy et al. 2007\textsuperscript{110}</td>
<td>19</td>
<td>8 week balance training on anteroposterior path of elderly</td>
<td>1.30%</td>
<td>0.18</td>
</tr>
<tr>
<td>Nagy et al. 2007\textsuperscript{110}</td>
<td>19</td>
<td>8 week training on mediolateral sway path of elderly</td>
<td>30.00%</td>
<td>4.17</td>
</tr>
<tr>
<td>Spennwyn 2008\textsuperscript{111}</td>
<td>30</td>
<td>Balance outcomes in fixed resistance equipment</td>
<td>49%</td>
<td>-</td>
</tr>
<tr>
<td>Panics et al. 2008\textsuperscript{112}</td>
<td>20</td>
<td>Proprioception training on knee joint position</td>
<td>170.90%</td>
<td>-</td>
</tr>
<tr>
<td>Sato et al. 2009\textsuperscript{113}</td>
<td>20</td>
<td>Core Strength training on Star Excursion balance</td>
<td>11</td>
<td>0.82</td>
</tr>
<tr>
<td>Schilling et al. 2009\textsuperscript{114}</td>
<td>19</td>
<td>Comparisons of activity-specific balance confidence pre and post intervention</td>
<td>4.10%</td>
<td>0.96</td>
</tr>
<tr>
<td>Kibele &amp; Behm 2009\textsuperscript{114}</td>
<td>40</td>
<td>7 weeks of instability training and traditional resistance training on balance testing on a wobble board: static balance</td>
<td>4.40%</td>
<td>1.5</td>
</tr>
<tr>
<td>Kibele &amp; Behm 2009\textsuperscript{114}</td>
<td>40</td>
<td>7 weeks of instability training and traditional resistance training on balance testing on a balance beam: dynamic balance</td>
<td>14.70%</td>
<td>0.67</td>
</tr>
<tr>
<td>Granacher et al. 2011\textsuperscript{115}</td>
<td>30</td>
<td>Balance training on postural sway in 6-7 year olds</td>
<td>7.80%</td>
<td>0.21</td>
</tr>
<tr>
<td>Granacher et al. 2011\textsuperscript{116}</td>
<td>32</td>
<td>Combined balance &amp; strength training on center of pressure displacement in middle-aged adults</td>
<td>11.70%</td>
<td>0.42</td>
</tr>
<tr>
<td>Ogaya et al. 2011\textsuperscript{117}</td>
<td>23</td>
<td>Wobble board training (9 weeks) in the elderly: standing on the wobble board</td>
<td>113%</td>
<td>1.17</td>
</tr>
<tr>
<td>Muelbauer et al. 2011\textsuperscript{118}</td>
<td>20</td>
<td>Center of pressure: Firm ground, eyes open vs foam ground, eyes open for two-legged stance</td>
<td>65.20%</td>
<td>2.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Center of pressure: Firm ground, eyes open vs foam, eyes open for step stance condition</td>
<td>32.10%</td>
<td>1.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Center of pressure: Firm ground, eyes open vs foam, eyes open for tandem stance condition</td>
<td>26.30%</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Center of pressure: Firm ground, eyes open vs foam, eyes open for one-legged stance condition</td>
<td>28.60%</td>
<td>1.64</td>
</tr>
</tbody>
</table>

**Total** 647 **Means** 105% 1.243
or IRT found no differences in force, static balance, or functional performance between the groups. All measures improved over time for both the unstable and stable trained groups. In the Sparkes and Behm study, there was a trend (p=0.08) for the unstable training group to increase unstable forces to a greater extent. In other words, the instability-trained subjects could exert greater forces when experiencing an unstable environment. Since in the every day environment, unstable situations can arise such as slipping on an icy sidewalk, wet grass or a muddy patch, the ability to respond with higher forces could preclude or minimize chances for injury. However, if when performing unstable exercises there is a considerable decrease in force and power output compared to traditional stable exercises, how is it possible that prolonged IRT programs could provide similar strength training enhancements in the short term (i.e. 7-8 weeks) as compared to traditional stable RT programs?

The common finding of instability-induced decreased force or power compared to traditional RT exercises is not always accompanied by a similar impediment in muscle activation. Whether muscle activation is substantially reduced depends on the severity of the unstable condition. Many of the studies in the literature report that the demands of lifting while supported on an unstable surface cause an increase in core muscle activation, in order to maintain control. Increased core muscle activation when performing the same exercises under moderately unstable versus stable conditions has been shown when performing chest press, push-ups, and squats. Table 5 highlights a sample of studies that examined trunk stabilizer muscle activation when performing exercises under stable and unstable conditions. On average, trunk muscle activation increased by 47.3% with an effect size of 2.48 indicating a large magnitude of change. It should be noted that there is a substantial degree of variability between these studies. For example, Martins et al reported serratus anterior muscle activation deficits ranging from 27-106% when performing push-ups under unstable versus stable conditions. A rationale for these discrepancies is the extent of instability. Studies that implement a higher degree of instability can result in a decrease in muscle activation. For example, Behm et al had subjects perform either a leg extension or plantar flexion resistance exercise while seated on a stable bench or an unstable physioball. When performing the leg extensions, there was only one point of stable contact with the floor making this exercise more unstable compared to the plantar flexion exercise where both feet were in contact with the floor resulting in only moderate instability. Compared to the stable control condition, the more unstable leg extension exercise resulted in a 70.5% drop in leg extension force whereas the less or moderately unstable plantar flexion exercise caused a 20.2% decrease in force.

### Table 3. Sample of Studies Examining the Effect of Balance Training on Functional Measures.

<table>
<thead>
<tr>
<th>Authors(s)/Year</th>
<th>n</th>
<th>Intervention</th>
<th>% change</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myer et al. 2006</td>
<td>11</td>
<td>Dynamic stabilization and balance training on vertical jump</td>
<td>9.30%</td>
<td>0.75</td>
</tr>
<tr>
<td>Kean et al. 2006</td>
<td>7</td>
<td>Dynamic stabilization and balance training on hamstrings torque</td>
<td>17.40%</td>
<td>0.89</td>
</tr>
<tr>
<td>Yaggio et al. 2006</td>
<td>36</td>
<td>Fixed foot balance training on CMJ height</td>
<td>9.50%</td>
<td>0.57</td>
</tr>
<tr>
<td>Taube et al. 2007</td>
<td>23</td>
<td>Balance training effects on vertical jump</td>
<td>-0.05%</td>
<td>0.02</td>
</tr>
<tr>
<td>Oliver et al. 2009</td>
<td>8</td>
<td>Balance training effects on shuttle run time</td>
<td>3%</td>
<td>0.27</td>
</tr>
<tr>
<td>Functional balance training in collegiate women volleyball athletes on single leg squats (right)</td>
<td>80.9%</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Functional balance training in collegiate women volleyball athletes on single leg squats (left)</td>
<td>141.7%</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Functional balance training in collegiate women soccer athletes on single leg squats (right)</td>
<td>32.8%</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Functional balance training in collegiate women soccer athletes on single leg squats (left)</td>
<td>4.7%</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>85</td>
<td>Means</td>
<td>31.43%</td>
<td>0.585</td>
</tr>
<tr>
<td>Authors(s)/Year</td>
<td>n</td>
<td>Intervention</td>
<td>% change</td>
<td>Effect Size</td>
</tr>
<tr>
<td>-----------------</td>
<td>----</td>
<td>------------------------------------------------------------------------------</td>
<td>-----------</td>
<td>-------------</td>
</tr>
<tr>
<td>Stanforth et al. 1998&lt;sup&gt;122&lt;/sup&gt;</td>
<td>20</td>
<td>10 week resistaball training study on double leg lowering</td>
<td>49.60%</td>
<td>1.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 week resistaball training study on cybex back extension</td>
<td>156.20%</td>
<td>1.98</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 week resistaball training study on cybex abdominal</td>
<td>94.80%</td>
<td>1.09</td>
</tr>
<tr>
<td>Bruhn et al. 2004&lt;sup&gt;105&lt;/sup&gt;</td>
<td>33</td>
<td>Sensorimotor training on MVC</td>
<td>6.7%</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sensorimotor training on squat jump height</td>
<td>4.6%</td>
<td>0.21</td>
</tr>
<tr>
<td>Tsimaras et al. 2004&lt;sup&gt;123&lt;/sup&gt;</td>
<td>15</td>
<td>Muscle strength and dynamic balance ability training at 300 deg/s</td>
<td>20%</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Muscle strength and dynamic balance ability training at 60 deg/s</td>
<td>13.60%</td>
<td>0.41</td>
</tr>
<tr>
<td>Bruhn et al. 2006&lt;sup&gt;124&lt;/sup&gt;</td>
<td>18</td>
<td>Strength training &amp; sensorimotor training on muscle strength on development of bilateral 1 RM</td>
<td>37.00%</td>
<td>1.11</td>
</tr>
<tr>
<td>Carter et al. 2006&lt;sup&gt;106&lt;/sup&gt;</td>
<td>20</td>
<td>Stability ball training on static back endurance</td>
<td>30.30%</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stability ball training on side bridge test</td>
<td>5.70%</td>
<td>0.52</td>
</tr>
<tr>
<td>Gruber et al. 2007&lt;sup&gt;125&lt;/sup&gt;</td>
<td>33</td>
<td>Sensorimotor training on MVC</td>
<td>0.53%</td>
<td>0.05</td>
</tr>
<tr>
<td>Cowley et al. 2007&lt;sup&gt;126&lt;/sup&gt;</td>
<td>14</td>
<td>Instability training using stability ball platform on 1RM strength during barbell chest press exercise</td>
<td>15.50%</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Instability training using flat bench platform on 1RM strength during barbell chest press exercise</td>
<td>17.40%</td>
<td>3.8</td>
</tr>
<tr>
<td>Thompson et al. 2007&lt;sup&gt;127&lt;/sup&gt;</td>
<td>18</td>
<td>Club Head speed results in older golfers after functional training</td>
<td>4.90%</td>
<td>0.53</td>
</tr>
<tr>
<td>Cressy et al. 2007&lt;sup&gt;128&lt;/sup&gt;</td>
<td>19</td>
<td>10 weeks lower body unstable surface training on Bounce drop jump power</td>
<td>0.8%</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 weeks of lower body unstable surface training on CMJ power</td>
<td>0.0%</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 weeks of lower body unstable surface training on 40 yard sprint time</td>
<td>1.8%</td>
<td>0.82</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 weeks of lower body unstable surface training on T-test times</td>
<td>2.9%</td>
<td>1.33</td>
</tr>
<tr>
<td>Cowley et al. 2007&lt;sup&gt;129&lt;/sup&gt;</td>
<td>14</td>
<td>Instability resistance training on 1 RM strength during barbell chest-press on a stability ball</td>
<td>15%</td>
<td>3.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Instability resistance training work capacity during barbell chest-press on a stability ball</td>
<td>27%</td>
<td>3.02</td>
</tr>
<tr>
<td>Kibe et al. 2009&lt;sup&gt;14&lt;/sup&gt;</td>
<td>40</td>
<td>7 weeks of instability training and traditional resistance training on strength during leg extension</td>
<td>9.50%</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 weeks of instability training and traditional resistance training on shuttle run time</td>
<td>20%</td>
<td>0.2</td>
</tr>
<tr>
<td>Sekendiz et al. 2010&lt;sup&gt;128&lt;/sup&gt;</td>
<td>21</td>
<td>Swiss ball core strength training on trunk flexor strength</td>
<td>28.50%</td>
<td>1.19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Swiss ball core strength training on trunk extensor strength</td>
<td>23.60%</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Swiss ball core strength training on lower limb extensor strength</td>
<td>8.50%</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Swiss ball core strength training on lower limb flexor strength</td>
<td>36.50%</td>
<td>1.66</td>
</tr>
<tr>
<td>Sparkes &amp; Behm 2010&lt;sup&gt;15&lt;/sup&gt;</td>
<td>18</td>
<td>Instability resistance training (8 weeks) on MVIC unstable / stable force ratio</td>
<td>21%</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Instability resistance training (8 weeks) on CMJ</td>
<td>5.7%</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Instability resistance training program (8 weeks) on MVIC forces</td>
<td>23.6%</td>
<td>0.44</td>
</tr>
<tr>
<td>Saeterbakken et al. 2011&lt;sup&gt;129&lt;/sup&gt;</td>
<td>24</td>
<td>Core stability training on throwing velocity in female handball players</td>
<td>4.90%</td>
<td>0.2</td>
</tr>
<tr>
<td>Granacher et al. 2011&lt;sup&gt;116&lt;/sup&gt;</td>
<td>32</td>
<td>Combined balance &amp; strength training on CMJ in middle-aged adults</td>
<td>4.10%</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Combined balance &amp; strength training on plantar flexors MVC in middle-aged adults</td>
<td>19.30%</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Combined balance &amp; strength training on plantar flexors isokinetic force in middle-aged adults</td>
<td>16.50%</td>
<td>0.49</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>339</strong></td>
<td><strong>Means</strong></td>
<td><strong>22.0%</strong></td>
<td><strong>0.98</strong></td>
</tr>
</tbody>
</table>
Table 5. Sample of Studies Examining EMG Data Under Stable versus Unstable Conditions - Trunk Stabilizer Muscle Activity

<table>
<thead>
<tr>
<th>Authors(s)/Year</th>
<th>n</th>
<th>Intervention</th>
<th>% change</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vera-Garcia et al. 2006</td>
<td>8</td>
<td>External oblique muscle performing a curl up on a stable bench vs. moderate instability</td>
<td>101.80%</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>External oblique muscle performing a curl up on a stable bench vs. extreme instability</td>
<td>-15.50%</td>
<td>-</td>
</tr>
<tr>
<td>Behm et al. 2005</td>
<td>11</td>
<td>EMG for lumbosacral erector spinae during stable exercises vs. unstable exercises</td>
<td>4.70%</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EMG for lower abdominal stabilizers during stable exercises vs. unstable exercises</td>
<td>27.90%</td>
<td>0.82</td>
</tr>
<tr>
<td>Anderson &amp; Behm 2005</td>
<td>14</td>
<td>EMG activity of the abdominal stabilizer muscles during the smith machine squat vs. unstable squat</td>
<td>29.60%</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EMG activity of the abdominal stabilizer muscles during the free squat vs. unstable squat</td>
<td>18.60%</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EMG of the lumbo-sacral erector spinae during the free squat vs. unstable squat</td>
<td>22.90%</td>
<td>4.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EMG of the lumbo-sacral erector spinae during the smith machine squat vs. unstable squat</td>
<td>20.00%</td>
<td>6.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EMG of the upper lumbar erector spinae during the smith machine squat vs. unstable squat</td>
<td>33.80%</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EMG of the upper lumbar erector spinae during the free squat vs. unstable squat</td>
<td>22.90%</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EMG of the soleus during the smith machine squat vs. unstable squat</td>
<td>73.10%</td>
<td>16.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EMG of the soleus during the free squat vs. unstable squat</td>
<td>58.50%</td>
<td>10.7</td>
</tr>
<tr>
<td>Marshall et al. 2006</td>
<td>12</td>
<td>Transversus abdominus during squats performed with a stable surface vs. swiss ball</td>
<td>-56.70%</td>
<td>0.35</td>
</tr>
<tr>
<td>Marshall et al. 2006</td>
<td>14</td>
<td>Transversus abdominus with a swiss ball vs. stable surfaces</td>
<td>-57.10%</td>
<td>0.48</td>
</tr>
<tr>
<td>Freeman et al. 2006</td>
<td>10</td>
<td>Right erector spinae during push-up: no legs vs. standard</td>
<td>4.50%</td>
<td>0.04</td>
</tr>
<tr>
<td>Norwood et al. 2007</td>
<td>15</td>
<td>Latissimus dorsi under stable and dual instability conditions</td>
<td>-85.20%</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Erector spinae under stable and dual instability conditions</td>
<td>180.50%</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transversus abdominus/internal oblique</td>
<td>875.90%</td>
<td>1.9</td>
</tr>
<tr>
<td>Sternlicht et al. 2007</td>
<td>41</td>
<td>Stability ball crunch with a traditional crunch on upper rectus muscle</td>
<td>-30.70%</td>
<td>0.44</td>
</tr>
<tr>
<td>Bressel et al. 2009</td>
<td>12</td>
<td>50% of 1RM vs. BOSU trainer with free weight sqat exercise on transversus/internal oblique</td>
<td>-12.70%</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50% of 1RM vs BOSU trainer with the free weight sqat exercise on erector spinae</td>
<td>10.70%</td>
<td>0.21</td>
</tr>
<tr>
<td>Willardson et al. 2009</td>
<td>12</td>
<td>Transverse abdominus/internal oblique activity for Back Squat stable 50% of 1RM vs. BOSU 50% of 1RM</td>
<td>-26.90%</td>
<td>0.64</td>
</tr>
<tr>
<td>Schwanbeck et al. 2009</td>
<td>6</td>
<td>Erector spinae activity for Back Squat stable 50% of 1RM vs. BOSU 50% of 1RM</td>
<td>14.50%</td>
<td>0.34</td>
</tr>
<tr>
<td>Kohler et al. 2010</td>
<td>30</td>
<td>Erector spinae with a free weight sqat to smith machine squat</td>
<td>-45.50%</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower erector spinae with a shoulder press under unstable load/unstable surface vs. stable load/stable surface conditions</td>
<td>24%</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Upper erector spinae with a shoulder press under unstable load/unstable surface vs. stable load/stable surface conditions</td>
<td>37%</td>
<td>0.49</td>
</tr>
</tbody>
</table>

**Total** 185 **Means** 47.33% 2.48

Whereas quadriceps activation diminished 40.3% (highly unstable), plantar flexor activation remained relatively stable with an insignificant decrease of 2.9% (moderately unstable). Therefore, to achieve or maintain a sufficient extent of muscle activation, the degree of instability should be moderate rather than high. For example, while standing on a physioball may be an impressive feat of balance, attempting to perform resis-
Contrary to studies that report greater core muscle activation when comparing similar unstable exercises to stable exercises with similar absolute resistance, there is compelling evidence that traditional RT exercises such as squats and dead lifts with typical strength training resistance (i.e. 70-80% of 1 RM) produced greater activation of the erector spinae muscles versus unstable callisthenic exercises. Willardson et al reported greater rectus abdominis and transversus abdominis/internal oblique activity and no significant differences for the external obliques and erector spinae when performing an overhead press with 75% of 1RM under stable conditions versus 50% of 1-RM on a hemispherical BOSU® ball. In summary, Willardson and colleagues did not report any advantage for core activation when training with a hemispherical BOSU® ball. However, it is sometimes difficult to entice recreational or novice fitness enthusiasts or persons involved in rehabilitation to consistently train with loads equal to 75-80% or more of their 1 RM. For these individuals, the lower force and comparable EMG activity under unstable conditions may help in their motivation to adhere to a training program.

Based on the near linear force-EMG relationship, muscle activation correlates well with force output. If with moderate instability, force is depressed but activation is not substantially affected; according to the force-EMG relation, there must be a force component missing. The similar extent of muscle activation accompanied by decreased force with instability exercises when compared to traditional RT exercises suggests that the dynamic motive forces of the muscles (the ability to apply external force) may be transferred into greater stabilizing functions (greater emphasis on isometric contractions). Again this would be beneficial for rehabilitation purposes as it is inadvisable to force a recuperating weaker muscle to exert extremely high forces. However, according to the orderly recruitment of motoneuron concept, low intensity contractions tend to predominantly activate the lower threshold, slow twitch, type I fibres. For rehabilitation purposes, it may be more productive if a greater spectrum of muscle fibers could be activated and subjected to healthy stress to accelerate the recovery process. The use of a moderately unstable environment would allow the combination of lower external forces to be placed on the recuperating muscles albeit with a relatively higher degree of activation, which through both motive and stabilizing functions would provide positive training adaptations for a wider range of muscle fibers. These positive training adaptations may apply to the prevention and recuperation of both core (trunk) and limb injuries and in cases of degeneration.

**EFFECT OF INSTABILITY ON CO-CONTRACTIONS**

Generally, co-contraction activity increases when training on unstable support surfaces. The role of the antagonist under unstable or uncertain conditions would primarily be to control the position of the limb when producing force. Antagonist activity is reported to increase when uncertainty exists in the task. Increased antagonist activity may also be present to increase joint stiffness and hence stability. Furthermore, co-contractions are important for joint protection in order to safeguard joints from excessive forces.

While increased antagonist activity could be utilized for joint and muscle protection, to improve motor control, balance, and mechanical impedance (opposition to a disruptive force), it would also contribute to force deficits during unstable conditions by providing greater resistance to the intended motion. However, continued training may result in less co-activations. The instability-induced higher muscle activation and co-contractions while exerting lower force which could be an advantage for rehabilitating injuries such as sprains and strains, might not be as appropriate for some other conditions such as osteoarthritis. Based on the assumption of near linear force-EMG relations, the high muscle activation should produce similar amounts of internal force production. In conjunction with instability-induced greater co-contractions, internal muscle and joint tension could be high which could lead to compressional pain with an arthritic joint. Hence, caution should be used if recommending IRT in a rehabilitation setting for those with osteoarthritis, as internal muscle tension may remain high.

**LOW BACK PAIN (LBP)**

A strong trunk or core provides a base for the torques generated by the limbs when performing daily and
Reeves and colleagues explained that training the core musculature improves the robustness of the stabilizing system, potentially protecting against low back injuries. Durall et al indicated that there were no new incidences of low back pain (LBP) reported in collegiate gymnasts that participated in a 10-week core muscle-training program that incorporated progressive manual loading of the side bridge and prone back extension exercises in addition to their normal trunk flexion exercises. The progressive application of IRT exercises may play a strategic role with the prevention and treatment of LBP. Specific training to ameliorate the stabilizing functions of spinal muscles is an important factor in the rehabilitation of LBP. Increased strength of low back muscles is not the most important consideration for the prevention of LBP. However, increased strength can provide some protection when higher torques are generated with certain athletic skills or work-related tasks. Factors that are more highly correlated with LBP are decreased muscular endurance and impaired neuromuscular coordination. To ensure spinal stability, there must be coordinated activation of the core musculature. Hubley-Kozey et al noted greater consistency with the activation sequences of abdominal wall muscles during a supine bilateral leg-raising task among individuals that were better able to control lumbopelvic motion. This finding was especially apparent during phases of the task in which the hips and knees were extended, creating greater resistive torque.

Panjabi proposed that an active neural subsystem controls the recruitment of the core musculature with feed-forward and feedback mechanisms. Feed-forward mechanisms are pre-planned motor programs in preparation for movement, whereas feedback mechanisms are utilized to fine tune motor programs as skills are performed with greater efficiency over time. The objective of IRT is to stress the feed-forward and feedback systems to reprogram them for healthy and efficient functioning. Hence, the prevention of LBP and in some cases limb and joint injuries can be based on the ability of the core muscles to anticipate and respond to movement in order to stabilize the vertebral system.

Since the stiffness of a vertebral joint can be achieved with contractions as low as 25% of MVC and the efficiency of the multifidus can be improved with training loads of 30-40% of MVC, it is unnecessary to use excessive loads. Furthermore, since type I (slow twitch) fibers comprise the majority (>80%) of the erector spinae, multifidus, and longissimus thoracis muscles in healthy males and females, lower loads with higher repetitions should be the most appropriate training stress for the prevention or rehabilitation of low back problems. Even with the instability-induced lower forces outputs (compared to similar stable exercises); the higher instability-induced muscle activation, and the use of higher repetitions will ensure an increase in muscle fiber recruitment and eventual activation of higher threshold motor units (type II; fast twitch). Therefore, the low back stabilizing musculature can respond positively to multiple sets that involve high repetitions (e.g. >15 per set) especially under unstable conditions. Supporting the body on an unstable surface will elicit an increase in core muscle activation to maintain postural equilibrium during a given exercise. Jorgensen et al demonstrated moderate to high activation levels (i.e. 60-80% MVC) of the rectus abdominis, external oblique abdominis, erector spinae, and trapezius in untrained women that performed progressively more difficult versions of the supine bridge, quadruped, side bridge, and prone plank. These findings suggest that for untrained individuals, the utilization of body mass and manipulation of resistive torque via postural adjustments can sufficiently load the core musculature to increase strength and localize muscular endurance.
EFFECTS OF MOTOR CONTROL ON LOW BACK PAIN (LBP)

Appropriate coordination or motor control of the core muscles may be as or more important than the extent of trunk muscle activation or strengthening in patients with LBP.\textsuperscript{50} There are numerous studies that report motor control deficits of the core muscles with patients with LBP.\textsuperscript{51,52,67} Deep trunk stabilizers (i.e., transversus abdominus and multifidus) respond with anticipatory postural adjustments (APA) to movements of the upper or lower limbs.\textsuperscript{51,52,68} In healthy individuals, the activation of stabilizing muscles precedes the instant of force application.\textsuperscript{69,70} Individuals with LBP tend to display delays or disruptions in this protective APA.\textsuperscript{51,52} A delayed reflex response of trunk muscles is reported to be a risk factor for low back injuries in athletes.\textsuperscript{71} Furthermore, Radebold et al\textsuperscript{72} reported that the antagonist muscle group was delayed in contracting while the agonist was delayed in relaxing during quick trunk flexion and extension with chronic LBP. Chronic LBP has also been associated with early or over recruitment of certain stabilizing muscles. Ferguson et al\textsuperscript{73} found that the erector spinae with chronic LBP subjects contracted earlier and longer during lifting tasks compared to healthy controls. Exercises that can re-program appropriate anticipatory, concomitant postural adjustments as well as appropriate motor coordination to deactivate the appropriate muscles upon movement completion would be important for the prevention and rehabilitation of LBP.

Furthermore, the sensitivity of afferent feedback pathways can be improved with balance and motor skill training,\textsuperscript{67} resulting in quicker onset times of stabilizing muscles.\textsuperscript{74} For example, a back extensor rehabilitation-program of two weeks duration reduced reaction times in patients with LBP to a similar time as that of healthy controls.\textsuperscript{75} IRT may promote agonist-antagonist co-contractions with shorter latency periods that allow for rapid stiffening and protection of joint complexes.\textsuperscript{13} Thus, exercises that can improve the coordination\textsuperscript{60,67,76} and extent\textsuperscript{60,77} of core muscular activation potentially enhance the prevention and rehabilitation of LBP as well as accompanying extremity injuries. Traditional RT can accomplish the same muscle activation goals but may necessitate the use of greater resistances. On the other hand, compared to traditional RT exercises, instability-based exercise programs appear to require more complex and difficult movements for ongoing progression.\textsuperscript{29} Thus neither stable nor unstable resistance training should be considered as an overall panacea.

PREVENTION OF INJURIES TO THE EXTREMITIES

Neuromuscular control problems can increase the chances for lower back and extremity injuries.\textsuperscript{78-81} The incidence of ankle sprains in a group of volleyball players was reduced with balance training,\textsuperscript{82} which may be related to the improved discrimination of ankle inversion movements found with wobble board training.\textsuperscript{83} Similarly, the use of Tai Chi has been reported to improve knee joint proprioception\textsuperscript{84} and functional balance\textsuperscript{85} in elderly individuals. IRT exercises have been reported to be effective in decreasing the incidence of LBP and improving the sensory efficiency of soft tissues that stabilize the knee and ankle joints.\textsuperscript{40,76,86} The APA used to pre-stiffen joints prior to movement is not unique to the spine and has been shown to occur in peripheral joints as well.\textsuperscript{87} The contraction of the upper trapezius, biceps and rotator cuff of the shoulder complex\textsuperscript{87} has been shown to occur in anticipation of movement in healthy subjects. Therefore, IRT of the upper body may help to improve stability of the shoulder joint. IRT may improve both muscular balance and strength which may be useful in prevention of sports injuries and also aid in the recuperation of individuals who cannot withstand heavier loads or high resistance.

UNILATERAL TRAINING AS A FORM OF INSTABILITY

Instability can also be achieved without unstable devices such as balls, wobble boards and foam rollers. Typically, resistance exercises are more often bilateral using either a barbell or a pair of dumbbells. However the majority of activities of daily living, occupational tasks and sport actions are unilateral (e.g., tennis, squash, baseball),\textsuperscript{88} and thus unilateral exercises may be more beneficial because they adhere to the principle of training specificity.\textsuperscript{89} Behm et al\textsuperscript{90} reported greater erector spinae activation during the unilateral shoulder press and greater transversus abdominus and internal oblique activity with the unilateral chest press. Rather than using an unstable device, unilateral resisted actions may provide a disruptive torque to the
body, thus providing another type of unstable condition. Hence, an effective strategy to activate the spinal stabilizers while training the upper limbs would be to use one dumbbell during the action. Unilateral contractions can also stimulate neural activity in the contralateral but inactive limb, referred to as cross education. Other studies have reported crossover fatigue effects from a unilateral exercise to the same contralateral limb with the leg extensors, biceps brachii, and dorsal interosseus (minor effects). Therefore, by training the contralateral healthy limb, the injured limb will receive neural stimulation and may maintain greater strength, while also stimulating activation of the core muscles.

CONCLUSIONS
Some of the characteristics of IRT exercises that are not conducive to optimal strength or power training for athletes, may be favorable for rehabilitation. The instability-induced deficits in force compared to traditional stable RT exercises, which dampen the strength training stimuli in trained individuals, can be of sufficient intensity for a recuperating muscle. While, these lower external forces exert less, but healthy stress on a more injury-susceptible joint, the less dramatic changes or even increases in trunk and limb muscle activation provide greater stabilizing functions to protect recovering muscles and articulations. Greater coordination training challenges with instability exercises should promote motor control adaptations (i.e. co-activations, anticipatory postural adjustments) that are especially important with LBP conditions. Physical therapists should consider IRT as a progressive component in the rehabilitation training program that may begin with solely balance training (no load), progressing to balance challenges with resistance (IRT) to traditional ground based RT with greater loads and intensities.

ACKNOWLEDGEMENTS
The authors would like to acknowledge the contributions of Ms. Carrie Ryan in compiling the summary data for the tables within this manuscript.

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ABSTRACT

As the number of youth sports participants continues to rise over the past decade, so too have sports related injuries and emergency department visits. With low levels of oversight and regulation observed in youth sports, the responsibility for safety education of coaches, parents, law makers, organizations and institutions falls largely on the sports medicine practitioner. The highly publicized catastrophic events of concussion, sudden cardiac death, and heat related illness have moved these topics to the forefront of sports medicine discussions. Updated guidelines for concussion in youth athletes call for a more conservative approach to management in both the acute and return to sport phases. Athletes younger than eighteen suspected of having a concussion are no longer allowed to return to play on the same day. Reducing the risk of sudden cardiac death in the young athlete is a multi-factorial process encompassing pre-participation screenings, proper use of safety equipment, proper rules and regulations, and immediate access to Automated External Defibrillators (AED) as corner stones. Susceptibility to heat related illness for youth athletes is no longer viewed as rooted in physiologic variations from adults, but instead, as the result of various situations and conditions in which participation takes place. Hydration before, during and after strenuous exercise in a high heat stress environment is of significant importance. Knowledge of identification, management and risk reduction in emergency medical conditions of the young athlete positions the sports physical therapist as an effective provider, advocate and resource for safety in youth sports participation. This manuscript provides the basis for management of 3 major youth emergency sports medicine conditions.

Key words: youth sports injuries, sudden cardiac death, concussion, heat related illness, hydration
INTRODUCTION

In the United States today, greater than 40 million children and adolescents participate in youth sports.\(^1,2\) In 2001 there were 2.6 million emergency department visits by athletes from 5 to 24 years of age and 500,000 physician visits by high school athletes in the United States.\(^1\) At that time, the estimated annual healthcare cost related to emergent care of the young athlete was two billion dollars.\(^1\) As sports participation has risen, so too has the incidence of injuries across the spectrum of severity, from mild to catastrophic. In 2010, the National Athletic Trainers Association reported 50 fatal sports related injuries in children.\(^3\) Currently across the United States there are multiple bills in legislation to prevent significant injuries to the youth athlete, however, as of 2010 only six percent have been enacted.\(^3\) Three focus areas of concern are concussion, cardiac arrest, and heat illness.\(^3\) With less than twenty percent of the 2 to 4 million youth athlete coaches in the United States receiving any formal training in coaching techniques, injury prevention, or first aid, the responsibility for emergency injury management as well as institutional, organizational, and community education is placed largely on the sports medicine practitioner.\(^2\) This clinical commentary will assist physical therapists in the recognition and management of acute sports related medical injuries and conditions which require special attention in the youth athlete.

CONCUSSION

Concussion in sport (CIS) continues to be a highly publicized and discussed topic among the national media and sports medicine practitioners. Since 2001, there have been three international symposiums on CIS, however none with a pediatric focus.\(^4\) Although the numbers of identified concussions occurring in the pediatric and adolescent population has continued to rise dramatically, appropriate management from acute injury to return to sport remains ill-defined and in its infancy. In 2010, the American Academy of Pediatrics (AAP) published a position statement on sports related concussions in children and adolescents thereby establishing basic management guidelines for the younger athlete.\(^4\) The majority of these guidelines were adapted from the 2008 Zurich symposium.

The number of US emergency department visits for 14 to 19 year olds due to concussions has tripled from 1997 to 2007.\(^6,7\) This group represented greater than forty percent of the concussions diagnosed in the emergency department during that timeframe and of those, between 30 and 58 percent were sports related.\(^6,7\) It is important to recognize that due to under reporting of symptoms in this population and the challenges associated with identifying this syndrome, the number of youth concussions is likely far higher than statistics indicate. Additionally, the data on elementary and middle school athletes is lacking in completeness.

Management of the youth athlete with a concussion is a multi-step process. Identification, sideline assessment, referral, medical symptom resolution, and return to sport are all key components. An understanding of the syndrome assists in emergency care. A concussion is the result of a direct blow to the head, chin or face by a moving or stationary object. Indirect biomechanical forces as a result of acceleration/deceleration or rotational forces of the brain within the skull are also causative factors.\(^8\) Recognition of a concussion is challenging as the seriousness of the syndrome is also not always consistent with the visualization of the injury and a young athlete’s brain may be more susceptible to injury than the adult brain due to immature tissue development. Additionally, less than ten percent of those athletes with a concussion experience loss of consciousness (LOC).\(^4,8\) Signs and symptoms of a concussion are listed in Table 1.

On field concussion assessment includes standard emergency care of airway, breathing and circulation assessment (ABC), as well as cervical and neurologic evaluation prior to moving the athlete to the sideline. (Figure 1) If the athlete is unconscious or reporting neck pain or neurologic symptoms, care for a cervical spine injury is necessary including facemask removal, appropriate spine boarding and transport to the emergency room.\(^9\) Seizures which accompany the concussive event also mandate immediate transportation to the emergency department. Initial sideline assessment also includes a subjective history about symptoms and events prior, during, and after the injury to assess for both retrograde and ante grade amnesia, a neurologic exam, and balance testing. Continued monitoring, and reassessing for an exacerbation of signs and symptoms is recommended at 15 minute
intervals throughout the first hour, then intermittently through the next 24 to 48 hours with mandatory physician follow up care, preferably with a physician who specializes in concussion. Various sideline assessment tools [Standardized Assessment of Concussion (SAC), Balance Error Scoring System (BESS), and Sport Concussion Assessment Tool 2 (SCAT2)] have been developed and implemented in adult athletes for concussion identification. The SAC test has shown good sensitivity and specificity outcomes, however, it has not been validated in the grade school athlete. The SCAT 2 combines the BESS and SAC testing and is currently being studied with prospective outcomes currently unavailable. Neurologic testing includes the “three C’s”: cognition, coordination and cranial nerves. Table 2 provides information regarding cranial nerve testing. The Glasgow coma scale may be utilized to identify a more serious head injury and a score less than 15 requires immediate referral to an emergency department. Addition-

<table>
<thead>
<tr>
<th>Physical</th>
<th>Cognitive</th>
<th>Emotional</th>
<th>Sleep</th>
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<tbody>
<tr>
<td>• Headache</td>
<td>• Foggy</td>
<td>• Irritability</td>
<td>• Drowsiness</td>
</tr>
<tr>
<td>• Nausea</td>
<td>• Feeling Slow</td>
<td>• Sadness</td>
<td>• Increased sleep</td>
</tr>
<tr>
<td>• Vomiting</td>
<td>• Difficulty concentrating</td>
<td>• Labile Affect</td>
<td>• Decreased sleep</td>
</tr>
<tr>
<td>• Balance difficulty</td>
<td>• Memory impairment</td>
<td>• Nervousness</td>
<td>• Difficulty falling asleep</td>
</tr>
<tr>
<td>• Visual disturbance</td>
<td>• Confusion of current events</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Fatigue</td>
<td>• Slow processing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Sensitivity to light and noise</td>
<td>• Repeated questions</td>
<td></td>
<td></td>
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<tr>
<td>• Dazed</td>
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<td></td>
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<tr>
<td>• Stunned</td>
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Figure 1. On field concussion assessment includes standard emergency care of airway, breathing and circulation assessment (ABC).
ally, deterioration in health status which includes excessive vomiting, worsening headache, impaired balance and coordination or slurred speech also warrants an immediate referral to an emergency department. Following most concussion injuries it is typical for neurologic imaging to be unremarkable. Computed Tomography is indicated if the athlete presents with a cervical spine injury, skull fracture, decline in symptoms, seizures, suspicion of an intracranial bleed, or a LOC greater than 30 seconds. While LOC is a parameter for the determination of imaging, grading scales which use LOC as the predictors of severity are no longer utilized or recommended by the AAP.

In a young athlete, identification or suspicion of a concussion necessitates removal of the athlete from sports participation for the rest of the day and until further evaluated by a physician. Both cognitive and physical rest are paramount to the appropriate management of a youth athlete with a concussion. These measures insure maximal recovery of neural tissue. Most adult athletes with concussions become asymptomatic within a week of their initial injury; however the younger athlete often takes seven to ten days or longer to recover. Additionally, because youth athletes are at elevated risk for a rare phenomenon known as second impact syndrome, a cautious return to sport is always recommended. Second impact syndrome appears to only occur in the pediatric and adolescent population and is the result of another concussive event to healing brain tissue prior to complete recovery of the initial injury. While the second event can be seemingly minor, the compounded effects are frequently catastrophic with high morbidity and mortality rates.

Once an athlete is asymptomatic at rest for twenty four hours, a symptom based approach is implemented for return to play with multiple tests used to identify whether symptoms have resolved. A clinical exam, neuropsychologic testing, balance and symptom reports at rest and with exertion are all used to identify concussion resolution and implementation of a return to athletics program. A five step sequence is used to progress the athlete safely back to sports participation. Progression to the next step occurs only if the athlete is symptom free for twenty four hours at the previous stage. This process requires a minimum of five days. Refer to Table 3 for general guidelines of the progression. In addition to physically challenging the athlete with a concussion, it is also important to challenge multiple

<table>
<thead>
<tr>
<th>CN II (Optic) – Visual acuity</th>
</tr>
</thead>
<tbody>
<tr>
<td>CN III (Occulomotor) – Pupillary reaction</td>
</tr>
<tr>
<td>CN IV (Trochlear) – Eye movement</td>
</tr>
<tr>
<td>CN VII (Facial) – Smile/Grimace</td>
</tr>
</tbody>
</table>

Table 2. Cranial Nerve Testing.

Table 3. Concussion Return to Play Guidelines for the Youth Athlete.

- Follows a sequential order
- Must be asymptomatic for 24 hours to progress to next level
- Symptom free with cognitive activity prior to start of physical activity

1. Light aerobic activity: light exertion, basic stretching and strengthening, simple balance exercises
2. Light to moderate exertion: increase aerobic endurance, low impact strengthening, movement and position changes
3. Moderate to aggressive exertion: impact activities, positional changes and head movement, unstable balance exercises, cognitive challenges, multiple system challenges
4. Functional Training: aggressive exertion, interval training, non contact sport specific exercises
5. Sport Specific Training: maximal exertion, high intensity, begin modified non contact practice
6. Gradual Return to play: practice prior to competition

The above table is adapted from the American Academy of Pediatrics guidelines and the University of Pittsburgh Medical Center concussion program.
systems (cognition, balance, coordination) simultaneously. An example would be a reactionary agility drill which requires the athlete to sprint to different colored cones being called out by the therapist in random order with a pattern that mandates rapid, repeated directional changes. It is also important to tailor the rehabilitation program to the demands of the athlete’s individual sport. For instance, a gymnast or figure skater needs to have the ability to spin or become inverted. A gradual asymptomatic progression into those activities would be required in that specific athlete’s return to sport program.

SUDDEN CARDIAC DEATH
Sudden death in the youth athlete is rare, and when it occurs eighty five percent of the cases are attributed to cardiac emergencies. Additional causes include heat illness, pulmonary disorders and drug induced system failure. About 50 combined high school and college cardiac deaths occur a year with a prevalence of 1:100,000 and 1:300,000 respectively. Additional causes include heat illness, pulmonary disorders and drug induced system failure. About 50 combined high school and college cardiac deaths occur a year with a prevalence of 1:100,000 and 1:300,000 respectively. The most common cause of cardiac death of athletes under the age of 30 is Hypertrophic Cardiac Myopathy (HCM). In most cases, HCM is the muscular enlargement of the left ventricle and the septum with disorganization of the heart muscle fibers called myofiber disarray. It is an inherited gene mutation that affects the heart muscle tissue and this dysfunction can lead to various cardiac complications which include: arrhythmias, blood flow obstruction, mitral valve problems, and sudden death. The symptomatology of HCM varies greatly among patients from uncomplicated health problems and daily lives to severe signs and symptoms of shortness of breath, chest pain or fainting. Youth athletes who have HCM are at risk for cardiac arrhythmias during strenuous exercise mostly because they are asymptomatic and unaware they have a problem. When one family member is identified as having HCM, all close relatives are encouraged to undergo cardiac screening including an echocardiogram. For the youth athlete, ventricular hypertrophy is usually absent until early adolescence. If predisposing factors are identified during a physician visit or a comprehensive pre-participation physical examination through family history, heart auscultation, and/or abnormal ECG findings, further investigation via an echocardiogram is warranted. (Figure 2) Any athlete suspected of having HCM is removed from participation until a complete cardiac evaluation is performed. An athlete with confirmed HCM is disqualified from most sports participation.

Sudden death often occurs without symptoms or warning. The mechanism of cardiac arrest is due to heart arrhythmias of ventricular tachycardia and ventricular fibrillation. Identification of athletes at risk, through pre-participation physicals,
access to quality medical care and observation of athletes who are showing signs of fainting, shortness of breath, or significant fatigue during sports participation is the key to prevention. When on the sidelines, the pre-established emergency response action plan for the event and the location of the nearest AED need to be known by all sports medicine personnel who are responsible for the care and safety of the athletes at that time. Immediate recognition and implementation of the EMS with initiation of CPR and AED is critical to survival.

Commotio Cordis is another cause of sudden cardiac death in the youth athlete. The instances are rare but catastrophic, with a survival rate of fifteen percent. It is estimated that one in 200,000 high school athletes will die as a result. Commotio Cordis is triggered by a direct blow to the chest wall over the heart with the exact timing of repolarization just prior to the “T” wave peak eliciting instantaneous cardiac arrhythmias. Blunt force to the chest wall can be caused by a baseball, softball, hockey puck or another athlete. Young male athletes between the ages of 5 to 15 appear to be the most at risk. Unlike HCM, commotio cortis occurs in healthy athletes with no cardiac pathology. The narrow, under developed and pliable chest wall of the youth athlete has been identified as a plausible contributor to the mechanism. The amount and rate of chest wall compression are also factors. The highest incidences of injury are associated with those athletes who compete in baseball followed by hockey, lacrosse, soccer, softball, and karate. Upon impact, at the specific time in the heart rhythm cycle, various arrhythmias can result such as ventricular fibrillation, ventricular tachycardia, brady arrhythmias, and idio ventricular rhythm. The athlete collapses immediately and prompt CPR and defibrillation is necessary for survival. According to the American Heart Association, each minute in delay of treatment decreases the chance of survival by ten percent. Injury prevention strategies include age appropriate safety balls, chest protectors, playing with children of comparable size and skill level, and AED accessibility. Although the above strategies are not without limitations, they should facilitate a dialogue amongst parents, coaches, lawmakers and sports medicine practitioners on better preventative techniques.

DEHYDRATION AND HEAT-RELATED ILLNESS

Exertional heat illness encompasses a broad spectrum of conditions from muscle cramps to heat exhaustion and heat stroke. For the young athlete, these clinical manifestations are the direct result of physical activity in hot and humid temperatures when the body has become dehydrated. Heat stroke is the third highest exercise-related cause of death in high school students in the United States and thousands of emergency department visits a year are due to heat related illness. High rates of morbidity and mortality occur in athletes with symptoms of heat stroke if appropriate emergency management is delayed. Signs and symptoms of the heat illness spectrum are listed in Table 4. To prevent death, immediate recognition and implementation of the EMS with initiation of CPR and AED is critical to survival. Caution return to play is advised only if complete resolution of symptoms and hydration are achieved. If the athlete is participating in multiple exercise sessions throughout the day, repeated bouts of muscle cramping should exclude the athlete from returning to play. Heat exhaustion is a more serious condition which requires prompt removal from participation. Hydration and body cooling are necessary to prevent further rise in core temperature. If the athlete is disoriented to safely ingest fluids, or becomes unconscious, immediate transportation to a medical facility is warranted. Heat stroke occurs when the core body temperature rises to 104ºF (40ºC) or greater as the body's thermoregulatory and central nervous systems collapse. It is a medical emergency and the Emergency Medical Services (EMS) is to be activated. Aggressive cooling of the body is necessary and cold water immersion is best. Alternative cooling methods are the use of a hose/sprinkling system and ice bags to the groin and under the armpits.

The susceptibility of the young athlete to heat related illness was previously thought to be a result of deficiencies in thermoregulation, a large surface to mass ratio, an increase in metabolic heat production, and a decreased ability to perspire. However, new research has demonstrated that when environmental conditions are controlled and athletes are hydrated, the risk of heat-related illness can be minimized.
conditions, physical exertion and dehydration are kept constant, adults and children respond similarly to heat.\textsuperscript{17,21} Rectal, skin temperatures, and cardiac performance have been shown in newer studies to be comparable in both populations.\textsuperscript{19} Therefore, the premise that youth athletes are more susceptible to heat-related illness because of their immature physiologic systems is being proved inaccurate and is no longer recognized.

### Table 4. Spectrum of Heat Illness

<table>
<thead>
<tr>
<th>Heat cramps and dehydration: Cautious return to play</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle cramps</td>
</tr>
<tr>
<td>Thirst</td>
</tr>
<tr>
<td>Fatigue</td>
</tr>
<tr>
<td>Light-headedness</td>
</tr>
<tr>
<td>Sweating</td>
</tr>
<tr>
<td>Flushed face</td>
</tr>
</tbody>
</table>

**Heat Exhaustion:** Remove from play

- Dizziness
- Rapid pulse
- Headaches
- Nausea
- Vomiting
- Loss of coordination
- Profuse sweating
- Core temperature less than 104°F (40°C)

**Heat Stroke:** Medical emergency, Call 911

- Core temperature of 104°F (40°C) or higher
- Hot dry skin
- Multiple system failure
- Delirium
- Convulsions
- Abnormal vital signs

### Table 5. Guidelines for the Treatment of Heat Related Illness

- Remove athlete from participation
- Hydrate with water or sports drink
- Cool the athlete
  - Move to shaded area
  - Remove gear
  - “Fan”/circulate air
  - Apply water to skin (“mist” with a spray bottle as an example)
  - Change clothing
- Monitor status
as a reason for heat-related illness by the AAP. Instead, the circumstances and conditions of youth athletes participating in high heat stress environments appear to be the predisposing factors for heat illness as compared to adults. Retrospective studies demonstrate that athletes respond differently to heat stress at various temperatures. Individual factors that increase the risk for heat related illness include decreased physical fitness, non-optimal body weight, lack of acclimation, dehydration, medications, infection, fever, and other complicated medical problems. Environmental and situational conditions which put the youth athlete at risk include high humidity and heat, high heat index or wet bulb-globe temperature, decreased air motion, decreased access to shade, a sudden heat wave which does not allow time for acclimation, too much clothing or athletic equipment, multiple practice sessions or games in the same day or back to back days, and inappropriate access to rest and rehydration. Although heat related illness can be serious, it can also be prevented with alterations in the above individual, environmental, and situational circumstances. Special attention should be paid to the heat index, which is a measure of environmental temperature and humidity for helping to determine if it is safe to play. Refer to Table 6 for prevention strategies.

**Table 6. Heat Illness Prevention Strategies**

<table>
<thead>
<tr>
<th>Athlete responsibility</th>
<th>Coaches, athletic directors responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Begin participation euhydrated</td>
<td>Heat index</td>
</tr>
<tr>
<td>Be healthy</td>
<td>Emergency response plan</td>
</tr>
<tr>
<td>Be well rested</td>
<td>Provide rest/ hydration breaks every 20 to 30 min</td>
</tr>
<tr>
<td>Absent of fever or infection</td>
<td>Wear only necessary safety equipment</td>
</tr>
<tr>
<td>Wear sunscreen</td>
<td>Helmet removal while on the sideline</td>
</tr>
<tr>
<td>Wear lightweight, light color, breathable clothing</td>
<td>Acclimatize athletes</td>
</tr>
<tr>
<td></td>
<td>Allow deconditioned athletes to exercise as tolerated</td>
</tr>
<tr>
<td></td>
<td>Provide shade, ice and water for cooling</td>
</tr>
<tr>
<td></td>
<td>Design tournaments with longer breaks</td>
</tr>
<tr>
<td></td>
<td>Change times, postpone or cancel competition if heat index dangerously high</td>
</tr>
</tbody>
</table>

**Hydration**

Maintaining optimal hydration status (euhydration) before, during and after athletic participation is necessary for assisting in prevention of heat related illness, optimizing performance, and aiding in recovery. (Figure 3) Small amounts of weight loss in children (one and two percent) due to fluid loss can have a significant negative impact on physiologic function and performance. Keeping the youth athlete hydrated is challenging. Often by the time a young athlete recognizes the sensation of thirst, the body can be dehydrated by one to two percent. Signs and symptoms of dehydration include thirst, dry mouth, fatigue, headache, dizziness, irritability, and muscle cramps. Youth athletes should be encouraged to drink even when they are not thirsty. Providing fluids that the athlete enjoys optimizes hydration. It has been demonstrated that adding flavoring to water increases consumption by forty five percent. A six to eight percent carbohydrate solution made with glucose appears to be ideal in many settings. In general, for activities lasting less than an hour, water is best, and activities that last longer than an hour or occur through multiple sessions in a day, a carbohydrate drink with electrolytes is recommended. Diluting a pre-made sports drink with a one to one ratio of water to sports drink is often more palatable for younger children. Fruit juice, soda and other carbonated beverages can have a negative impact on the GI system and should be avoided. Identifying the best combination of fluid intake for each individual athlete should be practiced prior to competition to maximize hydration and avoid unexpected complications such
as gastrointestinal upset. General fluid intake guidelines for children and adolescents are listed in Table 7. Caffeine, found in carbonized beverages and energy drinks should be considered an ergogenic aid and therefore should be used with caution in this population as it can also negatively impact performance.

**CONCLUSION**

Sports injuries in youth athletes are a leading reason for sports participation attrition, along with pressures from coaches, parents and peers.\(^2,23\) It is estimated that between 70 and 80 percent of youth athletes stop playing sports before high school. Statistics illustrate that only one in four younger star athletes become elite players in high school and only 1 in 16,000 high school athletes advance to professional status.\(^2\) Given this information it is likely that the focus in youth athletics should be to emphasize fun and long term involvement in exercise and sports. For a young athlete who has the potential for many years of sports participation in the future, the risks of returning him/her to competition or practice on the same day of a medical incident far outweigh the short term perceived benefits. Therefore, a knowledgeable and conservative approach to the care and prevention of youth athlete emergent sports medical injuries and conditions optimizes successful acute management and promotes the likelihood of long term sports participation.

**REFERENCES**


**Table 7. Hydration Guidelines for Adolescents and Children\(^{17,21}\)**

- **Preparation:** 20 min before
  - Adolescent: 8 to 10 oz
  - Children: 4 to 8 oz

- **During participation**
  - Adolescent: 6 to 12 oz every 20 min
  - Children: 4 oz every 20 min

- **After:** Rehydrate
  - Adolescent: for every pound loss replace with 20 to 24 oz
  - Children: for every pound lost, replace with 16 to 20 oz


ABSTRACT

Limitations in thoracic spine motion may be due to restrictions in contractile or non-contractile tissues. Joint mobilizations are indicated when hypomobility of a joint (non-contractile tissue) is identified. The ability for a patient to perform self-mobilizations of the thoracic spine and ribs may help maximize intervention outcomes. The purpose of this article is to describe a low cost, portable device which can be used for thoracic spine self-mobilization techniques.

CLINICAL SUGGESTION
THORACIC REGION SELF-MOBILIZATION: A CLINICAL SUGGESTION
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PROBLEM
Musculoskeletal pathology of the thoracic spine and ribs is often thought to be self-limiting in nature. Recent interest in the thorax from a clinical perspective has been related to the recognition of the thoracic spine and ribs not only as a source of local and referred pain but also the influence of thoracic spine mobility on movement patterns in other regions of the spine and the shoulder girdle. Range of motion (ROM) in the thoracic region is necessary for a number of daily activities and sporting tasks such as golf, throwing sports, tennis, and rowing. Dysfunction of the thoracic spine can also play a role in breathing difficulties and may be linked to postural issues in the later stages of life.

Movement of the thoracic spine is coupled with movement of the adjoining ribs. Thoracic extension involves concurrent posterior rotation (external torsion) and depression of the posterior ribs with elevation of the anterior ribs. Although difficult to separate thoracic spine motion from the movement of surrounding structures, accepted approximate normative values have been described for thoracic spine flexion (20° to 45°), extension (25° to 45°), side-bending (20° to 40°), and rotation (35° to 60°). These measures are often assessed clinically using a tape measure, standard goniometer, inclinometer, or via visual assessment.

Restrictions in motion have the potential to impact performance and may manifest as local or distant musculoskeletal pathology. Motion restrictions may be due to contractile or non-contractile structures, and interventions to address each specific tissue restriction can vary depending on the source of the involved tissue. Contractile restrictions (muscle tightness, trigger points) may be identified by examining physiological ROM and with muscle palpation, while non-contractile restrictions may be identified by examining joint arthrokinematics and classifying them as normal, hypermobile, or hypomobile. Contractile restrictions may be addressed via muscle stretching or manual interventions such as soft-tissue mobilization or sustained pressure. Joint hypermobility is usually addressed with therapeutic exercise to improve neuromuscular control while joint hypomobility may be addressed with manual interventions including joint mobilization and manipulation. Hypomobility of vertebral and costovertebral joints in the thoracic spine may prevent the patient from attaining full motion of the thorax. Most interventions to address thoracic spine mobility are dependent on the clinician providing the intervention. The ability for the patient to incorporate self-mobilizations of the thoracic spine into therapeutic exercise programs may help maximize intervention outcomes. Additionally, self-mobilizations are active interventions versus passive mobilization techniques provided by the clinician and may be useful in busy clinical environments (i.e. sports medicine clinic, athletic training room). The ability to perform thoracic spine self-mobilization techniques is often associated with the use of foam rollers. Although the use of the foam roller is common, associated costs as well as portability (airline travel) may limit use in some clinical environments.

SOLUTION
The self-mobilization techniques described involve the use of a device that can be easily made in any athletic training room, sports medicine clinic, or fitness facility. This device requires two tennis balls and half-inch athletic tape. The two tennis balls are held together, and tape is applied from one end of a tennis ball and encircled around crossing to the opposite end of the other tennis ball and back to the original starting point—making a complete ellipse shape (Figure 1). Continuous or separate strips of elliptically-shaped tape are applied, in this manner, until both tennis balls have been completely covered by athletic tape. One last strip of tape is applied with taut pressure perpendicular to the ellipse-shaped strips between the two tennis balls. This should further accentuate the groove between the two balls which will be helpful when aligning the device with the spinous processes of the thoracic spine during the self-mobilization intervention.

Thoracic Spine Mini-Crunches
The self-mobilization thoracic spine technique can be used in conjunction with mobilization interventions provided by a clinician. Joint mobilizations may be...
graded on a 5-point scale\textsuperscript{14} with grades III and V used to improve joint mobility. Although patients may not fully understand graded mobilizations, the clinician can educate the patient on the appropriate mobilization range dependent on treatment goals and patient tolerance. Initially a patient may only be able to tolerate mobilization which is performed into resistance or up to the limit of the range of motion (analogous to Grade III mobilization).\textsuperscript{15} The patient may progress to utilizing a small-amplitude movement performed well into tissue resistance (analogous to Grade IV mobilization).\textsuperscript{15} Thoracic spine mini-crunches provide the patient the ability to control mobilization intensity and may be performed in a supine position with arms crossed over the chest (Figure 2). Crossing the arms over the chest protracts the scapulae, allowing the tennis balls to contact the thoracic spine and ribs while minimizing contact with the scapulae. The device is placed at the desired level of mobilization along the thoracic spine, with the tennis balls resting lateral to the spinous process and the vertebral spinous process resting in the groove of the device (Figure 2a). Typically, the tennis balls would be placed one segmental level below the segment to be mobilized into extension. With arms crossed over the chest, the patient slowly raises their shoulders off of the ground for a count of 3 seconds and then back down to the ground (Figure 2c). Although there is little consensus regarding optimal number of sets or repetitions the authors suggest 2-3 sets consisting of 15 repetitive oscillations. During this maneuver, if the patient experiences intolerable pain or discomfort, the clinician may consider performing the exercise in an upright position with the tennis balls placed against a wall in order to decrease the force being placed on the transverse processes and ribs. Should the exercise continue to cause discomfort the clinician should explore other therapeutic options.

**Supine Arm Circles**

A second technique, called supine arm circles, may be used as a soft tissue mobilization. Some soft tissue dysfunction manifests in the form of trigger points, which may be alleviated with sustained pressure.\textsuperscript{16} Based on the placement of the device, this mobilization technique can be used to target costovertebral or costotransverse joints as well as muscles of the scapulothoracic region such as the rhomboid, trapezius, or levator scapulae muscles. The placement of the device should be at a point of discomfort; some patients might find relief from performing the exercise at several points in the thoracic area. This technique uses the device described previously and is performed in the supine position, with the device placed parallel to the thoracic spine (Figure 3a). The patient then forward flexes their shoulder to 90 degrees so that their arm is perpendicular with the ground (Figure 3b). Next, the patient rotates their shoulder in a clockwise or counterclockwise direction (i.e. traces small circles with their arm). Although there is no consensus regarding optimal number of sets or repetitions, the authors suggest

![Figure 1. Self-mobilization device preparation. a) Athletic tape is applied from one end of one tennis ball around to the opposite end of the other tennis ball then back to the starting point to form initial ellipse shape. b) Completed device with middle perpendicular strip applied.](image-url)
Figure 2. Thoracic Spine Mini-Crunches. a) Self-mobilization device is placed at the desired vertebral level for mobilization with the groove over the spinous process. b) Patient positioning with arms across chest. c) Patient raises shoulder off of the ground 5-6 inches (mini-crunch).

Figure 3. Supine Arm Circles. a) Self-mobilization device is placed at the desired position of mobilization parallel to the thoracic spine. b) Shoulder is forward flexed 90 degrees and arm is straight and perpendicular to the ground.
that the patient performs the exercise for 2-3 sets of 30-60 second bouts in both directions. Should the exercise cause discomfort, it may be modified in a similar manner as described for the thoracic spine mini-crunches.

**DISCUSSION**

Joint mobilizations are indicated when an impairment in joint mobility or a limitation in accessory joint motion is pathologic. Individuals with a history of back pain or referred pain that is suspected to be caused by a hypomobile joint in the thoracic region may benefit from these techniques. The ability of patients to perform a self-mobilization in the thoracic region may help maximize clinical rehabilitative outcomes, but joint mobilizations should not be used in patients with suspected fracture, hypermobile joints, neurological symptoms, or in individuals who are not comfortable performing the self-mobilization intervention.

**REFERENCES**

ABSTRACT

Purpose/Background: Excessive frontal plane motion and valgus torques have been linked to knee injuries, particularly in women. Studies have investigated the role of lower extremity musculature, yet few have studied the activation of trunk or "core" musculature on hip and knee kinematics. Therefore, this study evaluated the influence of intentional core engagement on hip and knee kinematics during a single leg squat.

Methods: Participants (n = 14) performed a single leg squat from a 6 inch step under 2 conditions: core intentionally engaged (CORE) and no intentional core engagement (NOCORE). Participants were also evaluated for core activation ability using Sahrmann's model, and the resulting scores were used to divide participants into low (LOWCORE) and high scoring (HIGHCORE) groups. All trials were captured using 3-D motion analysis, and data were normalized for height and time. Paired t-tests and repeated measures, mixed model MANOVAs were used to assess condition and group differences.

Results: The CORE condition, compared to NOCORE, was characterized by smaller right \( t(13) = 3.03, p = .01 \) and left \( t(13) = 3.04, p = .01 \) hip frontal plane displacement and larger knee flexion range of motion \( t(13) = 3.08, p = .009 \). Subsequent MANOVAs and follow-up analyses revealed that: (1) the CORE condition demonstrated smaller right and left hip medial-lateral displacement in the LOWCORE group \( p = .001 \), but not in the HIGHCORE group; (2) the CORE condition showed larger overall knee flexion range of motion across LOWCORE and HIGHCORE groups \( p = .021 \); and (3) the HIGHCORE group exhibited less knee varus range of motion across CORE and NOCORE conditions \( p = .028 \).

Conclusions: Intentional core activation influenced hip and knee kinematics during single leg squats, with greater positive effect noted in the LOWCORE group. These findings may have implications for preventing and rehabilitating knee injuries among women.

Level of Evidence: 2B, Cohort laboratory study, mixed model design

Key Words: Biomechanics, Core Musculature, Kinematics, Knee

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INTRODUCTION

It is widely accepted that excessive frontal plane motion and valgus torque in the knee contribute to an increased risk of anterior cruciate ligament (ACL) injuries.1 However, the reasons for the greater frontal plane motion are not well understood, as a lack of consensus exists in the explanations posited in the literature.2,3 The lack of consensus presents limitations to effective training of healthy individuals and to the rehabilitation of individuals with knee injuries.4,5

The majority of ACL injuries are non-contact in nature, often occurring when the foot is planted during a cutting motion or landing from a jump.6 During such activities, the knee is often subjected to excessive frontal plane motion, as a result of internal rotation of the hip, adduction of the femur, and external rotation of the tibia.7,8 The comparative risk of injury per exposure is 2 to 8 times greater in women than in men,9 and researchers have shown that women often exhibit greater knee frontal plane motion and valgus torques during dynamic activities than men, which has been shown to contribute to the greater incidence of ACL injury in this subgroup.7

Dynamic knee stability is achieved through the neuromuscular control of a multifactoral kinetic chain, as the knee is directly supported by the immediately surrounding muscles, yet is also dependent on more proximal muscles of the hip and trunk.2,10,11,12 Differences in neuromuscular control of the hip have been cited as an important source of sex differences in lower extremity movement patterns.12 Bohannon et al.13 identified 19% greater body weight-normalized hip abduction isometric strength in males than in females. Similarly, Cahalan et al.14 reported 39% greater hip external rotation torque in males versus females without normalization to body weight. Other researchers have investigated the role of the hip abductors in eccentrically controlling hip adduction during weight bearing activities.8 Claiborne et al.12 found that the hip abductors play a significant role in stabilizing the femur during unilateral weight bearing activities. Wilson et al.15 also found that weakness in the hip external rotators was associated with abnormal knee motion in both men and women. In contrast, in a study of women performing a step down task, Hollman et al. found that hip stability as quantified by knee valgus patterns was more related to gluteus maximus recruitment capacity (as measured with EMG) than gluteus maximus strength (as measured with dynamometry). This finding led Hollman et al11 to theorize that while gluteus medius strength may provide benefits in resisting adduction of the femur, these benefits are somewhat mitigated by the role the gluteus medius plays in the internal rotation of the femur at some positions of available hip range of motion. In other words, effective neuromuscular control of the lower extremity kinetic chain is subtly influenced by issues such as hip joint position, strength, and proprioception during functional activities. The variety of findings has led researchers to investigate additional anatomical regions in an effort to further describe the variability seen at the knee during unilateral functional tasks and during landing.

Knee motion during functional activities cannot be solely attributed to hip or knee musculature.4,10 While their study did not assess muscular contributions to lumbopelvic or core control, Claiborne et al.12 noted that only 22% of knee variability could be attributed solely to hip muscles surrounding the hip, pointing out the limitations of including only the lower extremity in analysis of functional activities such as cutting and landing. Consequently, researchers are increasingly looking at the role that core musculature may play in lower extremity function.16,17,15 Although not a universally-accepted definition, “core musculature” or “core” in this paper will be defined as “muscles of the trunk and pelvis that are responsible for the maintenance of stability of the spine and pelvis and help in the generation and transfer of energy from large to small body parts”, or from the trunk to the extremities.16,p.189 As this definition suggests, the core musculature, due to proximal position in the axial skeleton, can influence motion of distal segments in the appendicular skeleton. Existing work suggests that proximal core muscles, such as the transversus abdominis, obliques, and multifidi, play an important role in spinal stabilization, and that poor function of these muscles is associated with low back pain and dysfunctional movement patterns.18,19,20 Furthermore, a growing number of authors advocate that “core stability” contributes to improved function of the lower extremities during gross motor activities.15,21,22,16

No studies have specifically investigated the role of core engagement on lower extremity kinematics during a
functional task. Therefore, the purpose of this study was to determine how intentional activation of the core musculature affected hip and knee kinematics during a single leg squat. The authors hypothesized that purposeful core engagement – compared to in vivo core activity – would result in significant differences in hip and knee linear displacements and angular measures. A secondary purpose of this study was to compare the performance during the single leg squat between two groups, based on their scores on a common clinical measure for recruitment of core muscles. Based upon the authors' observations working with clinical populations, we hypothesized that individuals with lower core recruitment scores would differ in their lower extremity kinematics, compared to those who scored higher on this clinical measure for core recruitment.

**METHODS**

**Participants**

A quasi-experimental design was used to assess the combined effects of core engagement and recruitment scores on kinematic measures in the lower extremities. A sample of convenience consisting of fourteen women age 20 to 24 years (mean (SD): age of 22.0 (1.2) yrs, height of 170.7 (6.2) cm, weight of 62.8 (8.5) kg) participated in this study. Only healthy, college-age women were included in order to minimize confounding effects related to sex or health status. Participants were excluded if they reported current pain or injury to the lower extremities or torso (including the spine and abdominal cavity), or if they had a history of any lower extremity injuries or surgical procedures in the twelve months prior to testing. The study protocol was approved by Rockhurst University's Institutional Review Board, and all testing was conducted in the Human Performance Laboratory in the Department of Physical Therapy Education. Before testing, written informed consent was acquired from all participants following the federal guidelines related to research involving human participants. Demographic data were collected from each participant and are compiled in Table 1.

**Procedures**

All participants were assessed for their capacity to effectively recruit the “core stabilizers” using the lower abdominal strength test as described by Sahrmann as commonly used in the clinical evaluation of patients with low back pain. This evaluation model is based, in part, on the notion that the abdominal muscles provide important support for the spine during functional activities and low level muscle activation is needed for many tasks. For example, a study completed at Yale University suggests that only 2-3% of maximum voluntary activity of the abdominal muscles is needed to stabilize the spine during upright unloaded tasks. Thus, the Sahrmann protocol aims to assess this level of abdominal level muscle activation and contains 5 testing levels, each designed to make it increasingly difficult to maintain a neutral spinal position using the involved core stabilizers. During testing, the physical therapist places the participant in the supine hook lying position, and then palpates the participant's engagement of the lower abdominals with one hand and the spinous processes of the participant's lumbar spine with the other hand. The physical therapist then monitors the participant's spine as one hip is flexed passively to 90 degrees and the other lower extremity is then lifted from the supporting surface. In application, a participant would be scored as a “0” if she could elicit a palpable engagement of the lower abdominal muscles but could not maintain a spinal neutral posture when instructed to lift one foot from the supporting surface, and scored as a “1” if she could, and so on through the five increasingly challenging levels of the test (Table 2). Previous authors have found this a valid and reliable clinical measure of the capacity to isometrically recruit lower abdominal muscles involved in core stabilization. As a means of reducing the potential for measurement error related to inter-rater variability, one mem-

<table>
<thead>
<tr>
<th>Table 1. Characteristics of the participants (n = 14).</th>
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<td>Minimum</td>
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<tr>
<td>Age</td>
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<tr>
<td>Height (cm)</td>
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<tr>
<td>Weight (kg)</td>
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<tr>
<td>Core Rating</td>
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ber of the research team completed all assessments of core stabilization on the participants in this study. Each participant was tested using this model three times as a means of repeated measures assessment. Five participants scored 1 or 2 on the Sahrmann test, with the remaining participants scoring 0. Due to the small range, resulting scores were used to divide participants into a low-scoring group (LOWCORE: test score of 0) and a high-scoring group (HIGHCORE: test score of 1 or 2).

After assessment of core stability, a single leg squat (SLS) task using a six inch step was explained and demonstrated to each participant. Again, one member of the research team provided all demonstration and instruction to the participants as a means of minimizing confounding variables. The SLS was chosen because while it is a controlled movement, it is a dynamic maneuver that can be extrapolated to many functional activities such as landing, running and cutting, and it is widely used in contemporary physical therapy practice for evaluating lower extremity motion. Experimental conditions were standardized by having each participant perform the SLS using her dominant leg. Leg dominance was identified from an item on the intake questionnaire in which the participant identified which leg she used to kick a ball, as used in previous work. All participants were found to be right-leg dominant. Each participant performed two SLS. Starting with the toes pointing forward, the participant maintained the weight bearing, dominant (right) foot on the step and lightly touched the heel of non-dominant (left) foot on the ground during the squat (Figure 1). Once the participant's heel tapped the ground the participant returned to a standing position on top of the step. As a means of constraining the motor task in a way that minimized confounding variables, participants were allowed to practice the task until the speed and consistency of heel contact were satisfactorily completed within a three second timeframe as measured by a member of the research team using a timer. Participants performed the SLS under two conditions: performing the squat with or without core musculature engagement (CORE and NOCORE,
respectively). For the CORE condition, participants were instructed to engage their abdominal muscles as they had done during the Sahrmann test of core activation described above, and as is commonly done when teaching therapeutic exercise to patients undergoing physical therapy. Verbal cues only were used during this portion of the protocol. As no tactile cues were provided, no assessment was made on the quality of the core musculature engagement during this portion of the testing. The order in which the participants completed the CORE and NOCORE conditions was randomized to prevent order bias.

All participants wore their own athletic shoes and shorts during testing. The shirts and shorts were adjusted to reveal the anterior superior iliac spines (ASIS) of each participant. Retroreflective markers (12.7 mm) were placed on bony prominences of each subject’s left and right ASIS (LASI and RASI), lateral femoral condyle of the dominant leg (RKNE) and lateral malleolus of the dominant leg (RANK).

Measurements
Marker positions were tracked in three dimensions during each SLS using an Ariel Performance Analysis System (APAS) 2007 (Ariel Dynamics, Inc., San Diego, CA, USA) with two Panasonic PV-GS320 digital video cameras (Panasonic Corporation of North America, Secaucus, NJ, USA), each positioned at 45 degrees to the participant and operating at a sampling rate of 60 Hz. The APAS motion analysis system has been found valid and reliable and is widely used in biomechanics research.26,29,30 All corresponding three-dimensional data underwent a three Hz low pass digital filter to smooth marker trajectories.

Data Analysis
All data was imported and processed using MATLAB R2009b (The MathWorks, Inc., Natick, MA, USA). Each participant’s data sequence was time normalized to 0-100% of the SLS duration to reduce variation among participants and allow direct comparison between trials. Motion data was used to create joint angle data sequences: knee flexion and varus angles were defined as sagittal and frontal-plane projection angles subtended by one line connecting the RASI and RKNE markers and a second line connecting the RKNE and RANK markers; hip abduction angle was defined as the frontal-plane projection angle subtended by one line connecting the RASI and LASI markers and a second line connecting the RASI and RKNE markers.11 Joint ranges of motion for knee flexion ($\theta_{\text{knee,flx}}$), knee varus ($\theta_{\text{knee,var}}$), and hip abduction ($\theta_{\text{hip,abd}}$), defined as the difference between maximum and minimum values, were extracted from joint angle data sequences. Since excessive frontal plane knee motion is often associated with ACL injury as discussed above, motion data sequences were also used to define maximum joint marker displacements, defined as the difference between maximum and minimum marker positions in the medial-lateral direction for RASI ($d_{\text{RASHIP,mla}}$), LASI ($d_{\text{LASHIP,mla}}$), and RKNE ($d_{\text{RKNE,mla}}$) markers. Similarly, since knee flexion range of motion is often associated with higher function when performing a squat during sporting and other functional activities,16,31,32 motion data were also used to define maximum joint marker displacements in the vertical direction for RASI ($d_{\text{RASHIP,ver}}$), LASI ($d_{\text{LASHIP,ver}}$), and RKNE ($d_{\text{RKNE,ver}}$) markers. All displacement variables were normalized to participant height (cm).

STATISTICAL METHODS
Statistical analysis was performed with SPSS 17.0 (SPSS, Inc., Chicago, IL, USA). To address the pri-
mary purpose of the study, paired t-tests were utilized to compare the CORE and NOCORE conditions in regards to joint marker displacement and ranges of motion. To correct for the effect of multiple comparisons, the Bonferroni method was applied to groups of variables (hip displacements, hip range of motion, knee displacements, and knee range of motion) to obtain corrected alpha values of .0125, .05, .025, and .025, respectively. To address the secondary purpose, 2 X 2 mixed model repeated measures multivariate analyses of variance (MANOVA) were conducted to investigate the interaction between core stabilization test scores (HIGHCORE and LOWCORE) and core activation condition (CORE and NOCORE), with core condition used as a within-participant factor and stabilization score as a between-participant factor. Separate MANOVAs were performed on the same groups of variables described above (hip displacements, hip range of motion, knee displacements, and knee range of motion). Bonferroni corrections were applied within each analysis to correct for the effects of multiple comparisons.

RESULTS

Effects of Core Engagement on Hip Kinematics
Mean (SD) normalized displacements (normalized displacements are expressed in centimeters relative to participant height in centimeters) for both right and left hips were 0.05 (0.02) and 0.06 (0.02) for the CORE and NOCORE conditions, respectively. Paired t-tests revealed significant core engagement effects on hip frontal plane displacement, but not angular range of motion. The CORE condition, compared to NOCORE, was characterized by smaller hip displacements, as measured by $d_{\text{RHIP, lateral}}$ [t(13) = -3.03, p = .01] and $d_{\text{LHIP, lateral}}$ [t(13) = -3.04, p = .01].

Effects of Core Engagement on Knee Kinematics
Mean (SD) knee angular range of motion was 55.78 (6.55) degrees and 54.47 (6.17) degrees for CORE and NOCORE conditions, respectively. Paired t-tests revealed significant core engagement effects on hip frontal plane displacement, but not angular range of motion. The CORE condition, compared to NOCORE, was characterized by smaller hip displacements, as measured by $d_{\text{RHIP, lateral}}$ [t(13) = -3.03, p = .01] and $d_{\text{LHIP, lateral}}$ [t(13) = -3.04, p = .01].

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group Mean (SD)</th>
<th>Comparison</th>
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<tr>
<td>Hip Displacement</td>
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<tr>
<td>$d_{\text{RHIP, vertical}}$ (cm/cm)</td>
<td>CORE 0.09 (0.02)</td>
<td>t=2.02 p=.064</td>
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<td></td>
<td>NOCORE 0.09 (0.02)</td>
<td></td>
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<tr>
<td>$d_{\text{LHIP, vertical}}$ (cm/cm)</td>
<td>CORE 0.05 (0.02)</td>
<td>t=-3.03 p=.010†</td>
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<tr>
<td></td>
<td>NOCORE 0.06 (0.02)</td>
<td></td>
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<tr>
<td>$d_{\text{HIP, lateral}}$ (cm/cm)</td>
<td>CORE 0.12 (0.02)</td>
<td>t=2.31 p=.038</td>
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<td></td>
<td>NOCORE 0.11 (0.01)</td>
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<tr>
<td>Hip Range of Motion</td>
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<tr>
<td>$\theta_{\text{hip,abd}}$ (degrees)</td>
<td>CORE 15.26 (3.44)</td>
<td>t=0.15 p=.883</td>
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<tr>
<td></td>
<td>NOCORE 15.11 (3.76)</td>
<td></td>
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<tr>
<td>Knee Displacement</td>
<td></td>
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<tr>
<td>$d_{\text{RHKE, vertical}}$ (cm/cm)</td>
<td>CORE 0.06 (0.01)</td>
<td>t=0.91 p=.378</td>
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<tr>
<td></td>
<td>NOCORE 0.06 (0.01)</td>
<td></td>
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<tr>
<td>$d_{\text{LHKE, vertical}}$ (cm/cm)</td>
<td>CORE 0.03 (0.01)</td>
<td>t=0.35 p=.732</td>
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<tr>
<td></td>
<td>NOCORE 0.03 (0.01)</td>
<td></td>
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<tr>
<td>Knee Range of Motion</td>
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<td></td>
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<tr>
<td>$\theta_{\text{knee,fix}}$ (degrees)</td>
<td>CORE 55.78 (6.55)</td>
<td>t=3.08 p=.009‡</td>
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<tr>
<td></td>
<td>NOCORE 54.47 (6.17)</td>
<td></td>
</tr>
<tr>
<td>$\theta_{\text{max, var}}$ (degrees)</td>
<td>CORE 7.71 (2.82)</td>
<td>t=1.16 p=.266</td>
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<tr>
<td></td>
<td>NOCORE 6.86 (2.14)</td>
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</table>

*Comparisons are based on normalized data, as displacement is expressed in centimeters (cm) relative to participant height in centimeters (cm).
†Significant core effect at the $\alpha = .0125$ level.
‡Significant core effect at the $\alpha = .025$ level.
tests revealed significant core engagement effects on knee angular range of motion, but not displacement. The CORE condition, compared to NOCORE, was characterized by larger knee flexion range of motion, as measured by $\theta_{knee,flx}$ $[t(13)=3.08, p=0.009]$. Effects of Core Activation Score and Core Engagement on Hip and Knee Kinematics

The MANOVA (Table 4) performed on hip displacements revealed a significant condition x core score interaction [Wilks’ Lambda = 0.22, F(4,9) = 8.11, p = .005]. Follow-up univariate analyses revealed that significant condition x core score interactions in $d_{RHIP\_lateral}$ $[F(1,12)=5.95, p = .031]$ and $d_{LHIP\_lateral}$ $[F(1,12)=7.31, p = .019]$ contributed to the multivariate interaction. Subsequent pairwise comparisons revealed no significant group differences for core score in $d_{RHIP\_lateral}$ within CORE (p = .167) and NOCORE (p = .772) conditions, or in $d_{LHIP\_lateral}$ within CORE (p = .211) and NOCORE (p = .643) conditions. Pairwise comparisons revealed significant CORE-related decreases in $d_{RHIP\_lateral}$ and $d_{LHIP\_lateral}$ within the LOWCORE group (p = .001 and p = .001, respectively), but not within the HIGHCORE group (p = .865 and p = .966, respectively). Although not contributing to the multivariate interaction, $d_{RHIP\_vertical}$ and $d_{LHIP\_vertical}$ were observed to have significant CORE-related increases within the LOWCORE group (p = .020 and p = .011, respectively), but not within the HIGHCORE group (p = .995 and p = .904, respectively).

The MANOVA performed on knee ranges of motion did not reveal a significant condition x core score interaction [Wilks’ Lambda = 0.82, F(2,11) = 1.23, p = .329]. However the MANOVA did reveal significant main effects for condition [Wilks’ Lambda = 0.51, F(2,11) = 5.34, p = .024] and core score group [Wilks’ Lambda = 0.41, F(2,11) = 7.85, p = .008]. Follow-up univariate analyses revealed a significant overall core-related increase in $\theta_{knee,flx}$ (p = .021), and a significant decrease in $\theta_{knee,var}$ for the HIGHCORE group, compared to the LOWCORE group (p = .028). Significant interactions and main effects for condition and core score group are depicted in Figure 2.

### Table 4. Results of 2x2 mixed model MANOVAs comparing hip and knee displacement and range of motion values within conditions (CORE and NOCORE) and between groups (LOWCORE and HIGHCORE).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>CORE Mean (SD)</th>
<th>NOCORE Mean (SD)</th>
<th>Condition Main Effect</th>
<th>Group Main Effect</th>
<th>Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip Displacement†</td>
<td>LOWCORE</td>
<td>0.09 (0.02)</td>
<td>0.09 (0.02)</td>
<td>F(1,12)=2.55 p=.137</td>
<td>F(1,12)=0.28 p=.609</td>
<td>F(1,12)=2.58 p=.135</td>
</tr>
<tr>
<td></td>
<td>HIGHCORE</td>
<td>0.09 (0.02)</td>
<td>0.09 (0.02)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LOWCORE</td>
<td>0.05 (0.02)</td>
<td>0.05 (0.02)</td>
<td>F(1,12)=7.38 p=.019</td>
<td>F(1,12)=0.37 p=.555</td>
<td>F(1,12)=5.95 p=.031</td>
</tr>
<tr>
<td></td>
<td>HIGHCORE</td>
<td>0.05 (0.02)</td>
<td>0.05 (0.02)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LOWCORE</td>
<td>0.11 (0.02)</td>
<td>0.11 (0.02)</td>
<td>F(1,12)=3.55 p=.084</td>
<td>F(1,12)=0.85 p=.374</td>
<td>F(1,12)=2.85 p=.117</td>
</tr>
<tr>
<td></td>
<td>HIGHCORE</td>
<td>0.11 (0.02)</td>
<td>0.11 (0.02)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LOWCORE</td>
<td>0.06 (0.02)</td>
<td>0.06 (0.02)</td>
<td>F(1,12)=7.68 p=.017</td>
<td>F(1,12)=0.18 p=.675</td>
<td>F(1,12)=7.31 p=.019</td>
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<tr>
<td></td>
<td>HIGHCORE</td>
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<td>0.06 (0.02)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip Range of Motion</td>
<td>LOWCORE</td>
<td>15.77 (3.82)</td>
<td>14.33 (2.74)</td>
<td>F(1,12)=0.13 p=.727</td>
<td>F(1,12)=0.02 p=.896</td>
<td>F(1,12)=3.23 p=.097</td>
</tr>
<tr>
<td></td>
<td>HIGHCORE</td>
<td>14.42 (4.46)</td>
<td>16.35 (1.79)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee Displacement</td>
<td>LOWCORE</td>
<td>0.06 (0.01)</td>
<td>0.06 (0.01)</td>
<td>F(1,12)=1.42 p=.257</td>
<td>F(1,12)=0.82 p=.384</td>
<td>F(1,12)=1.17 p=.300</td>
</tr>
<tr>
<td></td>
<td>HIGHCORE</td>
<td>0.06 (0.01)</td>
<td>0.05 (0.01)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee Range of Motion‡</td>
<td>LOWCORE</td>
<td>57.01 (6.06)</td>
<td>55.29 (5.17)</td>
<td>F(1,12)=7.06 p=.021</td>
<td>F(1,12)=0.64 p=.439</td>
<td>F(1,12)=1.87 p=.197</td>
</tr>
<tr>
<td></td>
<td>HIGHCORE</td>
<td>53.56 (7.51)</td>
<td>53.01 (8.13)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LOWCORE</td>
<td>8.69 (2.94)</td>
<td>7.65 (1.77)</td>
<td>F(1,12)=0.96 p=.346</td>
<td>F(1,12)=6.26 p=.028</td>
<td>F(1,12)=0.10 p=.752</td>
</tr>
<tr>
<td></td>
<td>HIGHCORE</td>
<td>5.96 (1.62)</td>
<td>5.44 (2.15)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Displacement measures are normalized to participant height (cm).
†Significant multivariate main effect for condition [F(4,9) = 7.88, p = .005] and condition x group interaction [F(4,9) = 8.11, p = .005] for hip displacement variables.
‡Significant multivariate main effect for condition [F(2,11) = 5.34, p = .024] and group [F(2,11) = 7.85, p = .008] for knee range of motion variables.
The MANOVAs performed on knee displacements and hip range of motion did not reveal any significant condition x core score interactions, condition main effects, or core score main effects.

**DISCUSSION**

The purpose of this study was to investigate the influence of intentionally activating the core musculature on lower extremity kinematics during a SLS. The findings suggest that activating the core in this way does affect hip and knee kinematics in women during a SLS. A secondary purpose was to examine the combined effects of intentional core engagement and core recruitment score on the performance measures. To achieve these goals, female subjects completed a SLS task with and without intentional core musculature engagement, during which performance measures were extracted from kinematic data captured during each trial. To study core effects alone, statistical comparisons were made between CORE and NOCORE conditions. To study the combined effect of core condition and core recruitment score, a 2 x 2 MANOV A was used.

The primary finding of the current investigation was that purposefully activating the core musculature did affect hip and knee kinematics in women during a SLS. Specifically, paired t-tests revealed core-related decreases in hip medial-lateral movement, suggesting that core activation contributes to greater frontal plane hip stability. This finding is consistent with Kaji and coauthors, who reported less medial-lateral motion in the frontal plane and smaller total excursions of center of pressure (COP) during quiet standing following core training. The results of the paired t-tests from the current study also revealed core-related increases in knee flexion range of motion, suggesting that core activation positively affected lower extremity function during the SLS task; based on the premise that greater knee flexion is a measure of higher function when performing a squat task during sporting and other functional activities.

These results are consistent with the idea of a feed-forward recruitment pattern of proximal to distal musculature. For example, Hodges and coworkers have done a number of studies showing that trunk muscle activity, specifically the transversus abdominis and multifidus muscles, in healthy individuals precedes the muscular activity in the extremities, whereas this characteristic is absent or reversed in individuals with movement dysfunction related to low back pain. It is believed that such a feed-forward recruitment pattern of core musculature provides a more stable neuromuscular foundation for movement to occur. Similarly, other authors have reported increased neuromuscular control at the hip as a significant contributing factor to knee kinematics. Interpreting the greater knee flexion during the CORE condition as greater distal mobility, the results of the current study support this theory of proximal stability promoting greater distal mobility in the lower extremities. However, the magnitude to which engaged core musculature prepares or influences lower extremity motion is not completely understood. Although the results demonstrated evidence of such a preparatory effect, finding a causal relationship of this effect is beyond the scope of the current study. Future studies should employ EMG measurements to further explore this phenomenon. Regardless of preparatory effect however, the results of this investigation may have implications for ACL injury, as incidence of injury has
been shown to decrease in athletes participating in training programs targeting core musculature.\textsuperscript{10,36}

A secondary finding was that individuals with lower scores on the core recruitment test demonstrated the greatest differences in performance between the CORE and NOCORE conditions. Specifically, our 2x2 MANOVA revealed that the CORE condition, compared to NOCORE, was associated with larger hip vertical displacement, smaller hip medial-lateral displacement, and greater knee flexion range of motion in the LOWCORE group, but not the HIGHCORE group. This finding illustrates that those with the poorest ability to activate core musculature exhibited the greatest change in lower extremity kinematics when the core was engaged, suggesting that LOWCORE participants had the most to gain from core activation. Given evidence that ACL injury risk is associated with low core performance ability,\textsuperscript{38} our results suggest that core training may have a greater impact among athletes with high ACL injury risk, compared to low-risk individuals. Similarly, core stability training has been shown to result in smaller movements of the center of mass trajectory during quiet standing.\textsuperscript{33}

Secondary analysis also revealed overall larger knee varus range of motion in the LOWCORE group, compared to HIGHCORE. This result indicates that LOWCORE participants had reduced ML knee stability compared to HIGHCORE participants regardless of voluntary core activation. This suggests that, although LOWCORE participants benefited from voluntary core activation, they may still have an elevated risk of injury in comparison to the HIGHCORE group. Such a finding provides additional evidence that training emphasizing core activation during functional tasks such as the SLS may help to reduce injury risk, as noted above, however, longitudinal studies would be helpful in further substantiating the impact of core training on lower extremity function in young women.

To the best of the authors' knowledge, this study is the first to compare the effects of voluntary core engagement on lower extremity kinematics at the hip and knee during a functional task. A clinical measure of core stability was obtained for each participant using the Sahrmann test for key core muscles (namely the transversus abdominis and internal and external obliques), which has been found reliable in previous studies.\textsuperscript{25,26,39} Other authors have investigated the influence of the hip musculature on hip and knee kinematics,\textsuperscript{11,12,40,31} and have demonstrated that activation of hip muscles does affect lower extremity motion and is therefore a predictor of knee injury.\textsuperscript{22,36,38} However, such studies have not identified the extent to which neuromuscular control of the trunk/core affects lower extremity kinematics. This study is an important link in demonstrating the influence of the tonic stabilizers of the core as measured by a common clinical test\textsuperscript{18,19,41,20} on the motion of the lower extremities.\textsuperscript{10,42,43} A logical next step would be to take the same basic approach of this study and apply it to clinical populations, and another logical next step would be to include electromyography as a means of better understanding how muscular recruitment patterns of the muscles in the axial skeleton influence lower extremity kinematics during functional tasks such as the SLS.

This investigation had a number of limitations. The methods used were aggregated from procedures used in previous research, but the context was different in the present study. For example, the Sahrmann method was used as means of assessing ability to
recruit core musculature. As in previous research and as in clinical practice, the authors administered this test with participants positioned in supine and it is unknown how well this assessment technique extrapolates to core activation or stabilizing ability in the standing position used during the SLS task. A related limitation is the subjective nature of the core engagement task during the SLS; no attempts were made to quantify the extent to which participants engaged the core musculature. Rather, the authors used a verbal command, a method widely used by physical therapists when teaching therapeutic exercise in clinical environments. Use of electromyography would address both of these limitations by providing: 1) a comparison between core engagement during standing, in comparison to the supine position used during the Sahrmann test; and 2) an objective assessment of participants ability to intentionally engage the core musculature. Still, the authors believe the current technique has merit since it is similar to what is commonly used in a clinical setting, as well as likely what will be used should practicing clinicians choose to integrate these or other findings into clinical practice.

Another limitation may have been the uniform step height for all participants. While this method is consistent with previous studies using the SLS, joint angles during the SLS may have been influenced by differences in participant anthropometrics. To minimize this effect, all data were normalized for height. The narrow age range of the participants also presented a challenge, limiting the capacity to generalize the findings to a broader population. Similarly, while statistically significant differences were found between a number of factors the study would have been strengthened with a larger sample size. Finally, the present study represents a single assessment of intentional activating the core on lower extremity kinematics. Future studies should employ longitudinal designs to investigate time-dependent effects of core activation, particularly in those who were in the low scoring group on the clinical assessment of core stability.

**CONCLUSIONS**

In the present study, core activation was associated with improved stability and mobility in terms of lower extremity kinematics during a single leg squat, and intentional core activation had the greatest influence on lower extremity kinematics in individuals with lower core recruitment scores. These results suggest that, with all else being equal, individuals with lower core scores may have more to gain from increasing core stability during lower extremity movement. These findings have clinically meaningful implications for individuals, particularly women, who may be at risk for knee injury during functional activities involving the lower extremities.

**REFERENCES**


37. Thüys Y, Van Tiggelen D, Willems T, De Clercq D, Witvrouw E. Relationship between hip strength and


ABSTRACT

Purpose/Background: Although side to side symmetry of lateral abdominal muscle thickness has been established in healthy individuals, it is unknown whether abdominal muscle symmetry exists in athletes with asymmetrical physiological demands, such as those of single-sided rowers. The purpose of this study was to examine the oarside versus the non-oarside lateral abdominal musculature thickness in collegiate single-sided rowers, as measured by ultrasound imaging (USI).

Methods: The study was a prospective, cross-sectional, observational design. Thirty collegiate crew team members (17 males, 13 females, age 19.8 ± 1.2 years) characterized as single-sided rowers participated. Resting muscle thickness measurements of the transversus abdominis (TrA), internal oblique (IO), and external oblique (EO) muscles were obtained via USI. Comparisons of absolute and relative muscle thickness between oarside and non-oarside were performed using paired t-tests. Potential differences based on gender, rowing experience, and history of low back pain were investigated using mixed model analysis of variance.

Results: There were no clinically significant differences in absolute or relative thickness of the TrA, IO or EO on the oarside versus the non-oarside. There were no significant side to side differences in the relative muscle thickness of the TrA, IO or EO based on gender, rowing experience, or history of low back pain.

Conclusions: In this sample of single-sided rowing athletes, no clinically significant side to side differences in lateral abdominal muscle thickness were observed. Despite the asymmetrical functional demands of single-sided rowers in this study, thickness of the lateral abdominal muscles was symmetric.

Level of Evidence: 4

Key Words: crew, sweep rowing, transversus abdominis, ultrasound imaging.
INTRODUCTION

Thirty-two percent of intercollegiate rowers experience back pain during their college career.¹ Many theories have been proposed to explain this high incidence of back pain such as exposure of rowers to cyclic loading in flexion and rotation, muscle imbalances of the back and leg muscles, and muscular dysfunction or motor control errors in maintaining spinal stability.¹²³⁴⁵ One may theorize that rowers who always row on the same side of a scull, known as single-sided or “sweep” rowers, could create side to side muscular imbalances and subsequently develop a greater risk for back pain.

During the rowing stroke, the trunk serves to both create and transfer forces from the legs and arms to the oar.¹ The lateral abdominal muscles provide trunk stability throughout the stroke to allow for powerful movements of the upper and lower extremities. The transversus abdominis (TrA), internal oblique (IO) and external oblique (EO) have been shown by electromyography (EMG) to be active during both the drive and recovery parts of the stroke, but are especially active in the latter part of the drive as an eccentric contraction to slow or control extension of the spine.¹ Because the single-sided rower consistently experiences asymmetric torque bias due to the demands of an off-set load from one oar, unilateral muscular demands may be placed on the abdominals and therefore create muscular asymmetries or imbalances.

Ultrasound imaging (USI) has been shown to be a reliable and valid non-invasive method for assessing the thickness of the lateral abdominal muscles. Hides et al⁶ validated resting measurements including thickness of the lateral abdominal muscles using magnetic resonance imaging (MRI) as the gold standard. Rankin et al⁷ showed excellent intrarater reliability when using USI to measure the lateral abdominal muscles with intraclass correlation coefficients (ICCs) across all muscles measured on the same day to be between 0.98-0.99 (95% confidence interval [CI]: 0.91-1.0) and across all muscles measured 7 days apart to be 0.96-0.99 (95% CI: 0.85-1.0).

There are several studies pertaining to symmetry of the lateral abdominal musculature using both MRI and USI.⁶⁷⁸⁹¹⁰ Abdominal symmetry can be explored by examining each of the lateral abdominal muscles with respect to their absolute thickness or their relative thickness. Relative thickness provides a value normalized to the individual and therefore may be a better measure. The relative thickness value is expressed as the percent thickness of the individual muscle in relationship to the total lateral abdominal thickness.² In healthy adults, Rankin et al⁷ found near perfect symmetry for all abdominal muscles when relative thickness of these muscles was assessed (all muscles exhibited less than 1.5% difference between sides). Few investigations regarding potential asymmetry of the abdominal muscles have been reported. Springer et al⁸ found no difference in TrA thickness based on hand dominance, and Springer and Gill⁹ found lateral abdominal thickness to be symmetrical in a lower extremity unilateral amputee population despite asymmetrical functional demands.

In contrast, Hides et al¹¹ reported abdominal asymmetry in athletes (elite cricketers) who participated in a sport that requires asymmetrical functional demands. Specifically, they found the IO was larger on the side contralateral to the dominant arm. The TrA, however, was found to be symmetric. Aside from the study by Hides et al¹¹, potential abdominal asymmetry has not been explored in athletes from other sports with asymmetrical physiological demands. Therefore, it is currently unknown whether abdominal asymmetry exists in other athletes, such as those who row on the same side of a scull.

The primary purpose of this study was to examine the oarside versus the non-oarside abdominal musculature in collegiate single-sided rowers, as measured by USI. The authors expected that no differences would be found outside of established abdominal muscle thickness symmetry normative values. A secondary purpose of this study was to examine any interaction effects between abdominal muscle thickness symmetry and gender, rowing experience, and history of back pain in collegiate single-sided rowers.

METHODS

Study Design

This was a prospective, cross-sectional, observational study approved by the West Point Institutional Review Board.
Subjects
Thirty collegiate crew team members out of a team of 70 rowers from the United States Military Academy Crew Team volunteered to participate in the study. Subjects were included if they were healthy, single-sided rowers. Subjects were excluded if they rowed bilaterally, or participated in the team in a capacity that was not solely rowing (coxswain or coach), or who had been injured or ill causing them to have missed training for more than two consecutive sessions at some point during the previous 6 weeks. Subjects were not excluded from the study if they experienced back pain at the time of the study, or during the previous 6 weeks, as long as the back pain did not interfere with the training as specified.

After completing the informed consent and information privacy paperwork, subjects completed an intake questionnaire with demographic information including age, gender, side of rowing (oar on left or oar on right side of scull), and incidence of back pain since the beginning of their rowing career. Those with current or a history of back pain completed a Modified Oswestry Disability Index (ODI) and a Fear Avoidance Behavior Questionnaire (FABQ) which included both a 7-item scale assessing fear-avoidance beliefs about work (FABQ work scale [FABQW]; score range, 0-42) and a 4-item scale assessing fear-avoidance beliefs about physical activity (FABQ physical activity [FABQPA] scale; score range, 0-24). Higher scores on the FABQW and FABQPA indicate that the individual has elevated fear-avoidance beliefs. High levels of test-retest reliability (ICC = .70-.90 for FABQ; ICC = .90 for ODI) and have been reported with these instruments.

Image Acquisition
Subjects were all given the same verbal instructions. They were instructed to lie supine on a plinth with the head resting at 15 degrees of flexion on a pillow and with their knees flexed over a pillow. Subjects were instructed to lie quietly and relaxed, with their arms behind their head, breathing comfortably while looking at the ceiling.

Ultrasound images were obtained using the Sonosite Titan (Sonosite, Inc., Bothell, WA) with a 5 MHz, 60 mm curvilinear array, and all measurements were performed by one evaluator. The evaluator was a Physical Therapist with 13 years of clinical experience and 5 years of experience working with USI. The evaluator was trained in the measurement technique to include a 4 hour group continuing education course and a subsequent 8 hour one on one training session with an experienced imager. The evaluator demonstrated excellent intrarater reliability measuring the lateral abdominals in this training session on 10 healthy individuals with an ICC of .97 for the TrA muscle, and .98 for the IO and EO muscles.

Images were acquired of the lateral abdominal muscles using the technique similar to Teyhen et al. (Figure 1). The center of the transducer was placed along the mid axillary line in the transverse plane just above the iliac crest. The transducer was positioned along the intersection of the hyperechoic portion of the TrA and the anterior reach of the lateral abdominal wall was placed on the far-left of the screen. The transducer angle was modulated slightly as needed to facilitate the best image of the fascial lines. The image was frozen at the end of the subject’s respiration and this served as the index image. The ultrasound machine was then placed in dual screen mode so that a second image of the same spot on the same side could be located and frozen. After measurements of the first two images were documented, the second image was unfrozen and a third image on the same side was captured, using the index image as a guide to ensure best possible placement of the transducer head on the same portion of the muscle. This sequence was then repeated on the opposite side. Three images were taken on each side.
Measurements
Measurements were performed similar to Teyhen et al. on all three images for each side and later averaged. The screen was covered in acetate and grease pencil markings were placed at the center of each dual screen input to identify the site where the measurements were taken, 3.5 cm from the insertion of the TrA into the anterior abdominal fascia. The evaluator was blinded to the oarside of the athlete.

Data Analysis
Descriptive statistics were completed for demographic information, history of back pain, and for the ODI and FABQ questionnaires. Dependent variables were absolute and relative thicknesses of the TrA, IO, EO, and total abdominals (TrA+IO+EO) at rest. The absolute thickness (mm) of the muscles was defined as an average of the three measurements which provides the optimal reduction in error. The relative thickness measurement (%) was defined using the following equation:

\[(\text{absolute individual muscle thickness/absolute total lateral abdominal muscle thickness}) \times 100\%
\]

For the primary purpose of this study, the independent variable was “side” (oarside, non-oarside). For the secondary purposes, the independent variables included gender, experience level (novice- less than 1 year rowing, advanced- more than 1 year rowing), and past/current history of back pain. Inferential statistics comparing the mean side to side absolute and relative thicknesses for the primary hypothesis were performed using 2-tailed paired t-tests, and the secondary aims were analyzed using 2x2 mixed model analysis of variance (ANOVA). The alpha level was set at .05 for all tests. Data were analyzed using SPSS Statistics v. 18.0 (SPSS, Inc., Chicago, IL).

RESULTS
Subjects
Thirty subjects enrolled and completed the study (17 males, 13 females; age = 19.8 ± 1.2 years). There were no exclusions from the study. Subjects were nearly evenly split on rowing side (16 right, 14 left sided rowers), had an average body mass index of 24.9 ± 0.8, the majority were experienced rowers (60% with greater than 1 year experience), and one-third (n = 10) reported current or previous back pain episodes. Subject demographics details are provided in Table 1.

<table>
<thead>
<tr>
<th>Table 1. Demographics of subjects (n=30).</th>
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<tbody>
<tr>
<td>Characteristics</td>
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<tr>
<td>Age (years; mean ± SD)</td>
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<tr>
<td>Male</td>
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<td>Height (cm; mean ± SD)</td>
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<tr>
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<tr>
<td>Rowing Experience (n)</td>
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<tr>
<td>Advanced (&gt; 1 year)</td>
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<td>Right Side</td>
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<td>Central/Bilateral</td>
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<tr>
<td>Modified Oswestry Disability Index (%)</td>
</tr>
<tr>
<td>Fear Avoidance Behavior Questionnaire</td>
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<tr>
<td>FABQW (mean ± SD)</td>
</tr>
<tr>
<td>FABQPA (mean ± SD)</td>
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</table>

BMI= Body Mass Index; FABQW= Fear Avoidance Beliefs Questionnaire work subscale; FABQPA= Fear Avoidance Beliefs Questionnaire physical activity subscale
Morphometry of the Lateral Abdominal Muscles

There was a significant difference in the absolute thickness of the TrA ($t = -2.17$, $p = 0.038$), oarside mean±SD of 4.5 ± 0.8 mm, non-oarside mean±SD of 4.7 ± 0.9 mm. There were no significant differences in the absolute thickness of the IO, the EO, or the total abdominal thickness from side to side ($t = -1.54$, 0.68, and 1.08, $p = 0.135, 0.503$, and 0.291 respectively) (Table 2).

There were no significant differences side to side in the relative thickness of the TrA or the IO ($t = -0.63$, –1.37, $p = 0.532, 0.183$ respectively), but there was a significant difference in the relative thickness of the EO ($t = 2.05$, $p = 0.050$) with an oarside mean±SD of 41.5 ± 4.7%, and a non-oarside mean±SD of 40.2 ± 5.0% (Figure 2).

There were no significant differences in relative thickness of the TrA, IO or EO based on gender ($p = 0.460, 0.915, 0.538$ respectively), experience in rowing ($p = 0.154, 0.622, 0.743$ respectively), or history of back pain ($p = 0.075, 0.602, 0.982$ respectively).

**DISCUSSION**

This study is the first to describe the morphology of the lateral abdominal muscles in single-side rowing athletes. The current study revealed a statistically significant difference in the absolute thickness of the TrA muscle between the oarside and the non-oarside of the subjects. However, this significant difference of only 0.2 millimeters between means would unlikely be considered to be clinically important. Additionally, the relative thickness of the EO muscle compared oarside to non-oarside was also statistically significantly different, but not likely clinically meaningful, since the means differed by only 1.3%. Recall that normative testing has shown side to side differences up to 1.5% in healthy populations. No differences in relative thickness between oarside and non-oarside lateral abdominal muscles were present, with respect to gender, experience level or back pain. Despite the asymmetrical demands of a single-sided rower, the current study results of abdominal symmetry are consistent with previous studies.

Symmetry between sides for the TrA may not be surprising. Hodges et al found that the TrA is activated before the other abdominal muscles during voluntary arm movements, independent of the direction of arm movements.

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**Table 2. Absolute thickness (mm) and mean difference side-to-side (mm) for resting measures in collegiate single-sided rowers.**

<table>
<thead>
<tr>
<th>Abdominal Muscle(s)</th>
<th>Oarside</th>
<th>Non-Oarside</th>
<th>Mean Difference</th>
<th>$t$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TrA</td>
<td>4.47±0.78</td>
<td>4.70±0.94</td>
<td>.23</td>
<td>-2.17</td>
<td>.038</td>
</tr>
<tr>
<td></td>
<td>(4.17 – 4.76)</td>
<td>(4.35 – 5.05)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO</td>
<td>10.69 ± 2.13</td>
<td>11.06 ± 2.47</td>
<td>.37</td>
<td>-1.54</td>
<td>.135</td>
</tr>
<tr>
<td></td>
<td>(9.89 – 11.48)</td>
<td>(10.14 – 11.98)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EO</td>
<td>10.37 ± 1.98</td>
<td>10.22 ± 2.25</td>
<td>.15</td>
<td>0.68</td>
<td>.503</td>
</tr>
<tr>
<td></td>
<td>(9.63 – 11.11)</td>
<td>(9.38 – 11.06)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>25.60 ± 3.83</td>
<td>26.01 ± 4.16</td>
<td>.41</td>
<td>-1.08</td>
<td>.291</td>
</tr>
<tr>
<td></td>
<td>(24.17 – 27.03)</td>
<td>(24.45 – 27.56)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Abbreviations:** TrA, transversus abdominis; IO, internal oblique; EO, external oblique; Total = TrA + IO + EO, measured value.

* Values expressed as mean ± SD (95% CI). $^\dagger p<.05$

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**Figure 2. Relative muscle thickness differences side to side (mean + standard deviation bars). Abbreviations: TrA, transversus abdominis; IO, internal oblique; EO, external oblique; $^\dagger P = .05$, $t = 2.05$.**
movement. They proposed that the main function of the TrA in trunk control lies in a general stabilization of the spine. Furthermore, Eriksson et al.\textsuperscript{24} recently demonstrated that expectation of a perturbation may result in a direction-independent function of the TrA muscle in lumbar spine control. Additionally, other researchers have demonstrated that contraction of the TrA muscle and the IO muscle are symmetric even in response to a unilateral limb lifting task and independent of unilateral presentation of LBP.\textsuperscript{25} If the primary function of the TrA is general stabilization, it seems plausible that it would be symmetrical in single-sided rowers, despite their asymmetrical demands.

The findings of symmetry in the oarside and non-oarside thickness of lateral abdominal muscles in single-sided rowers may be due to the kinematics of the stroke. Although the rowing stroke places unilateral demands through the abdominal musculature by a laterally off-set load, the rowing motion itself is not highly rotational through the torso when compared to some other asymmetric sports requirements. Perhaps athletes such as pitchers, power hitters, or tennis players would demonstrate more asymmetries in rotational muscles such as the IO and EO. Future research would be required to substantiate that theory.

It is also possible that the lack of side to side differences in lateral abdominal muscle thickness might be attributed to some mechanism in which rowers engage each side of the abdominal muscles (or each muscle) at different phases in the stroke, resulting in a balance that mitigates any measurable thickness differences at rest. EMG studies are lacking in the unilateral rowing athlete, and these types of studies could offer timing data about individual muscle utilization or recruitment throughout the rowing cycle for single-sided rowers.

The authors of the current study observed that 10 of the 30 subjects in our sample had a history of back pain which was similar to reports in previous studies of collegiate rowers.\textsuperscript{26,27} However, no side to side differences in abdominal muscle thickness of the oarside and non-oarside between those with and without a history of back pain were observed. In those having a history of back pain in this study, mean ODI scores measuring disability were under 8% and therefore considered low.\textsuperscript{13} Additionally, fear avoidance behaviors were low. Cut off values for abnormal fear avoidance for the behavioral scales have been previously defined as >29 for the FABQW and >14 for the FABQPA.\textsuperscript{28} The subjects in the current study scored below these cut offs for the FABQW, but slightly above (mean±SD, 15.8 ± 3.8) for the FABQPA. The higher score on the FABQPA is likely the result of the continued high level activity that these individuals are participating in, despite symptoms of low back pain. These scores, when viewed together, indicate that back pain was likely of minimal relevance in this sample of collegiate rowers.

A few limitations of this study should be considered. One limitation is that these subjects were military cadets who have many physical requirements. In addition to the unique demands of their sport they also participate in other physical training which may provide symmetrical forces on the trunk. However, this level of physical activity that also provides symmetrical movement is likely similar in other rowing athletes who must stay actively involved in general physical conditioning and cross-training activities outside of their normal crew practice.

Additional threats to validity occur in USI studies due to image acquisition or measurement errors. The authors attempted to limit these errors by performing a reliability analysis, using a dual screen display to ensure consistent positioning of the transducer, averaging multiple measures, and blinding the imager to the oarside of the subject to reduce bias.

**CONCLUSION**

In this sample of collegiate single-sided rowing athletes, no clinically significant side to side differences in lateral abdominal muscle resting thicknesses were observed using USI. While statistically significant differences in the relative thickness of the EO favoring the oarside were found, the mean difference between sides was small (1.3%) which is similar to published normative data. Further, no differences were noted in side to side comparisons of relative thicknesses when accounting for gender, experience in rowing, or history of low back pain. Despite the asymmetrical demands of single-sided rowers in this study, bilateral thickness of the lateral abdominal muscles was symmetric.
REFERENCES


17. Ainscough-Potts AM, Morrissey MC, Critchley D. The response of the transverse abdominis and internal oblique muscles to different postures. Man Ther. 2006;11:54-60.


ABSTRACT

Purpose/Background: The decision to return an athlete to sports following anterior cruciate ligament reconstruction can be controversial. The purposes of this study are 1) to describe a functional test (Vail Sport Test™) that includes the evaluation of muscle strength, endurance, power, and movement quality in those patients attempting to return to sports following ACL reconstruction and 2) to assess the reliability of the Vail Sport Test™.

Methods: A prospective cohort study design. A total of 30 (12 F, 18 M) subjects (18.1 ± 5.3 yrs) volunteered for the study. All subjects were post-operative ACL reconstruction (5.2 ± 1.9 months) and were in the process of returning to sports. Each subject completed the Vail Sport Test™ and was videotaped from the anterior and lateral view. The videotape was then viewed and graded at two different points in time (48 hours apart) by three licensed physical therapists. Intraclass correlations (ICCs) were calculated to determine intra- and inter-rater reliability.

Results: Intra-rater reliability was excellent with a range of .95 to 1.0. Reliability values between graders were .97 (ICC2,k) and 1.55 (SEM).

Conclusions: The results of this study suggest that the Vail Sport Test™ has excellent reliability when the same graders scored the test using video on repeated occasions. In addition, the test was reliable between different graders.

Level of Evidence: Level 2b
INTRODUCTION
The timeline for return to sports after anterior cruciate ligament (ACL) reconstruction is often debated and can be difficult to determine. Factors such as range of motion (ROM), strength, pain, outcome scores, and functional performance tests may be considered when deciding if a patient is able to return to sports.\(^1\) Because athletes are often returning to dynamic activities that involve large forces across the knee and may be at risk for re-injury, it is important that the measures used for evaluating a patient's readiness for return accurately assess the demands. Hop tests have been used as a measure of functional performance in the lower extremity\(^2\)–\(^5\) and are believed to effectively test a patient's strength and neuromuscular control.\(^6\) Additionally, they have been shown to be a reliable and valid outcome in patients who have undergone an ACL reconstruction.\(^3\) When forty-two post-operative ACL-reconstructed (ACLR) patients were tested on four consecutive occasions, reliability scores ranged from .82 to .93 while demonstrating significant longitudinal validity. The patient's test performance on the hop test is described as the leg symmetry index (LSI) and is measured by comparing the involved limb to the uninvolved limb and is expressed as a percentage.\(^3\) A score of 85% or less on the hop tests is considered to be abnormal.\(^7\) While hop tests are often considered to be an objective measure that replicates the demands of high-level sport activities,\(^8\) they may not be sensitive enough to identify some functional limitations due to their lack of multi-planar movements.\(^9\)

Measurements of muscle strength are also considered to be important following ACL reconstruction.\(^10\)–\(^14\) If ACLR patients do not regain full quadriceps strength, gait abnormalities are evident.\(^13\) When patients with quadriceps strength of greater than 90% of the uninvolved side (strong) were compared to a group of patients with quadriceps strength of less than 80% of the uninvolved side (weak) and ACL-deficient (ACLD) patients, the patients classified in the weak group demonstrated lower knee flexion angles during walking and jogging (similar to the ACLD group) than those classified in the strong group. However, strong group subjects were able to walk and jog with normal knee patterns, suggesting an ability to efficiently use the quadriceps.\(^13\) As the ACLR patient progresses toward sport-specific activities, the need for quadriceps strength increases. Based upon the literature, an ACL-reconstructed patient should be able to achieve isokinetic quadriceps peak torque of up to 85% of the uninvolved lower extremity in order to progress to plyometric activities.\(^12\) Similarly, a quadriceps strength index (percent strength of the opposite limb) of greater than or equal to 80% is believed to be important prior to these patients performing hop tests.\(^14\) Failure to achieve these markers may demonstrate a patient's inability to adequately dissipate forces, and thus be at risk for injury.

Power, or a patient's ability to produce a high force over a short period of time, is another return to sports factor that must be considered. Neeter et al.\(^11\) used a battery of tests to assess overall leg muscle power in ACLR patients. When patients who were 6 months post-op ACL reconstruction were tested on the knee-extension, knee-flexion, and leg-press power tests 90% were identified as having abnormal or decreased leg power on the reconstructed side. This test battery was determined to be sensitive enough to identify strength performance deficits between the injured and uninjured sides and thus, could be used to determine if ACLR patients are ready to return to sports.\(^11\)

The relationship between strength and function has been examined in regards to athletic performance;\(^4\)\(^15\)–\(^18\) however, there is some discrepancy in the literature when it comes to establishing this association. Isokinetic strength of hip abductors and adductors are not correlated with functional sideways hop tests in elite ice hockey players,\(^17\) and isokinetic quadriceps strength is not strongly correlated with one-legged hop tests in healthy college students.\(^4\) Conversely, the triple hop test has been shown to be a strong predictor of isokinetic quadriceps strength in Division I-AA college soccer players.\(^15\) In the injured population, isokinetic quadriceps strength has been shown to be related to functional tests in patients following ACL reconstruction.\(^16\)\(^18\) Petschnig et al\(^18\) found a significant correlation between quadriceps peak torque and single and triple hop tests in 55 ACLR males. Likewise, 31 patients who had undergone ACL reconstruction demonstrated a significant relationship between quadriceps strength indices (ratio of injured to uninjured limb) and single and
triple hop indices. In addition, the quadriceps strength of these patients was correlated with function as measured by a series of agility tests (shuttle run, side step test, and carioca tests) after surgery. Although these results suggest a relationship between strength and function as it relates to a patient's ability to return to sport, they do not involve an assessment on the overall quality of movement patterns during these tasks and did not identify those who could successfully return to sport.

A clinical tool for the identification of patients at high-risk for ACL injury has recently been established. Padua et al showed that individuals who demonstrate poor technique (more errors) during jump-landing tasks have different lower extremity kinematics and kinetics than those individuals who demonstrate excellent technique (fewer errors). As such, the Landing Error Scoring System (LESS) was developed and is considered to be a reliable and valid test for assessment of jump-landing techniques for sports that involve movements in multiple planes of motion. While this particular clinical tool has been used to screen those at risk for ACL injury, the same principles of identifying faulty movement patterns during dynamic tasks would seem to be useful in patients who are in the process of returning to sports.

While the assessment of strength, power, and function have all been identified as important factors in deciding when a patient is ready to return to sports-specific activities, each assessment alone has some limitations. Although a relationship between strength and function has been established, muscle endurance has not been accounted for. Likewise, if certain movement patterns predispose one to an ACL injury, similar measures of movement assessment during the return to sport phase after ACL reconstruction should be included. Therefore, the purposes of this study are as follows: 1) to describe a functional test (Vail Sport Test™) that includes the evaluation of muscle strength, endurance, power, and movement quality in those patients attempting to return to sports following ACL reconstruction; 2) to assess the reliability of the Vail Sport Test™. We hypothesized that the Vail Sport Test™ would prove to be a reliable tool when used in the assessment of a patient's readiness to return to sports following ACL reconstruction.

METHODS

Participants
Thirty ACLR patients (18 males, 12 females) who were in the process of rehabilitation volunteered and gave informed consent for this study. The surgical grafts used in the reconstructions included 11 hamstring, 11 patellar tendons, and 8 allografts while additional procedures involved 7 meniscus repairs and 8 partial meniscal resections. Each subject was in the return-to-sports phase of the rehabilitation process when they completed the Vail Sport Test™. The mean age of the subjects was 18.1±5.3 years and the average time from surgery was 5.2±1.5 months. Subjects were active in organized sports at the high school, college, or recreational level and presented with a mean pre-surgery Tegner Activity score of 7 and a mean post-surgery Tegner Activity score of 5 at the time of testing. The Institutional Review Board of Greenville Hospital System (Greenville, SC) approved the research procedures.

Procedures
The Vail Sport Test™ is a return to sports assessment that incorporates a series of dynamic multiplanar functional activities against the resistance of a sportcord®. There are a total of four components of the test that include a single-leg squat for 3 minutes (Video 1), lateral bounding for 90 seconds (Video 2), and forward/backward jogging for 2 minutes each (Videos 3 and 4). After each component, the patient is given 2.5 minutes to rest prior to proceeding to the next task. The patient is graded based upon the ability to demonstrate strength and muscular endurance, absorb and produce force, all while maintaining appropriate movement quality at the trunk and lower extremity. The potential scores for the individual components are as follows: the single leg squat and the lateral bounding both have a maximum award of 15 points, and the forward/backward jogging have a maximum award of 12 points each for a total composite score of 54 points.

The Vail Sport Test™ was videotaped from an anterior and lateral view and was graded at two different points in time (48 hours apart) by three licensed physical therapists with experience ranging between 3 and 18 years. Prior to grading, each grader completed a two-hour training session on how to correctly grade and
score the Vail Sport Test™. In addition, the graders were required to demonstrate proper understanding of the grading instructions by completing several practice tests as part of pilot testing.

Grading criteria for the Vail Sport Test™ includes assessment of technique for each component and is based on a binary scoring system (yes = 1, no = 0). One point is given for each standard completed with proper form during the time intervals of each of the four components. The total available points for the Vail Sport Test™ is 54 and a patient is required to score at least 46 out of 54 points (85%) in order to receive a passing score, although this has not been established in the research. The patient does not receive a point for the chosen standard if they continue to perform with an incorrect movement pattern (after they have received verbal feedback) on 3 consecutive repetitions within each time interval (Appendix). As an example, if, during the first minute of the single leg squat, the patient performs the movement with dynamic knee valgus 3 times in a row despite having been given feedback, then he or she would lose a point for that particular minute. These criteria are constant for each standard and component of the Vail Sport Test™. For the single leg squat the subject must perform each repetition at a cadence of 1 second up and 1 second down against resistance of a sportcord® as it is stretched away from the wall and the other the measured distance of the subject's leg length from the first piece of tape. Grading of the task involves the patient performing each repetition as follows: 1) the knee flexes at least 30° upon the foot contacting the ground, 2) without dynamic knee valgus, 3) performs repetitions within landing boundaries, 4) the landing phase does not exceed 1 second in duration, and 5) without the trunk falling excessively forward or to the side. Because the duration of this component is 1.5 minutes, the scoring is broken into assessment of each of the criteria in 30 second intervals (1st 30 seconds, 2nd 30 seconds, 3rd 30 seconds). The subject receives one point for each criterion that is performed correctly during each 30 second interval for a maximum total of 15 points. For instance, if the subject demonstrates proper movement and technique on all of the criteria during the 1st 30 seconds and 2nd 30 seconds, but is unable to control their forward trunk lean on 3 consecutive repetitions in the last 30 seconds, then they would lose the point for that criterion and would consequently score 14 out of 15 points. The rationale for the lateral bounding is for the patient to demonstrate good absorption (knee excursion), power (landing phase time), and neuromuscular control (avoiding poor movement patterns) during lateral movements.

The final components of the Vail Sport Test™ are forward and backward jogging against resistance of the sportcord®. As with the lateral bounding, the sportcord® is attached to an immovable object at waist height to provide resistance by pulling the patient toward its attachment point. This attachment is the same for both the forward and backward jogging. The patient is instructed to hop from one leg to the other in an up and down manner (similar to jogging in place) while using proper form and absorbing energy with each landing by bending at the knee (primary) and hip (secondary). The patient is expected to perform each repetition 1) with the knee excursion between 30° and 60° of flexion, 2) within landing boundaries, 3) without dynamic knee valgus, 4) without locking the knee during extension, 5) without the landing phase exceeding 1 second in duration, and 6) without the trunk excessively falling forward or to the side during landing. Similar to the lateral bounding component, rationale for forward and backward jog-
ging includes the patient demonstrating good absorption (knee excursion), power (landing phase time), and neuromuscular control (avoiding poor movement patterns) during sagittal plane landing movements.

**Data Analysis**

The total score for each subject’s Vail Sport Test™ was calculated after watching the video and a total score was given on both occasions the video was graded. Each grader was allowed to watch the video one time during the grading portion with the ability to pause and rewind as needed. The scores for each graded session were then compared across all three graders (inter-rater) and between each individual grader (intra-rater). Intra-class correlations (ICCs) were calculated to determine intra-(2,1) and inter-rater reliability (3,k). All analyses were calculated using SPSS version 19.0 (Chicago, IL 60606).

**RESULTS**

When the scores of the three graders were calculated for all 30 subjects, the average Vail Sport Test™ score was 45 (±10.2) out of a total of 54 possible points. Representative scores of the individual components of the test included single leg squat (13.0±3.0), lateral bounding (11.9±2.9), forward jogging (10.1±2.7), and backward jogging (10.0±3.6). Table 1 outlines specific scores for each gender.

Intra-rater reliability agreement was excellent with a range of .95 to 1.0 (ICC2,1). Reliability testing between testers demonstrated excellent inter-tester agreement with an ICC value of .97 (ICC2,1) and 1.55 (SEM). Reliability for the four individual components of the Vail Sport Test™ is as follows: single leg squat .92 (ICC2,1) and .84 (SEM); lateral bounding .85 (ICC2,1) 1.25 (SEM); forward jogging .92 (ICC2,1) and .84 (SEM); backward jogging .99 (ICC2,1) and .41 (SEM).

**DISCUSSION**

The results of this study suggest that the Vail Sport Test™ is a reliable measure of physical performance in ACL-reconstructed patients when the same graders scored the test on repeated occasions. Likewise, the test was also shown to be reliable between graders. While this test has previously been used as a measure of physical performance following ACL injury20 and hamstring avulsion reconstruction,21 until now there has been a lack of evidence with regard to the overall reliability of the test.

Although there are several functional tests reported in the literature that are used to assess return to sports after ACL reconstruction,3,16,22,23 they may not fully represent the high demands encountered in sports while also assessing the overall quality of movement. While hop tests are often used and have been shown to be reliable in patients undergoing rehabilitation following ACL reconstruction,3 there may be limitations in the ability of these tests to assess muscle endurance and movement quality in multiple planes of motion. With the Vail Sport Test™, each component requires the patient to demonstrate not only muscle endurance, but also the qualitative ability to control the lower extremity during the task.

Even if return to sports tests contain components with stimuli high enough to simulate a patient’s sport-specific activities, assessment of quality of movement and compensation can be difficult. Keays et al16 examined knee strength and functional stability in post-operative ACL patients with the use of tests such
as the shuttle run, side step, carioca, and hop tests. Quadriceps strength was significantly correlated with both hop indices and agility tests in patients following ACL reconstruction. Similarly, when ACL reconstruction patients were compared to controls in bipedal functional tasks such as shuttle and agility runs, there were no significant differences between groups. However, when these same patients were tested on single leg performance tasks, the patients who had undergone ACL reconstruction demonstrated deficits in the reconstructed limb. These results suggest that although bipedal functional measures of shuttle and agility tests may be more representative of a patient’s required demands when returning to sports, they may be not sensitive enough to detect single limb performance deficits.

A clinical tool (Landing Error Scoring System – LESS) used for screening athletes who may be at risk for ACL injury during landing has been developed and studied. While this tool may often be used as a means of identifying those in need of an ACL prevention program, assessing overall movement quality in multiplanar movements may also be warranted in the return to sports phase of rehabilitation after ACL reconstruction. Grading of the Vail Sport Test was designed with constructs similar to the LESS in order to allow the clinician to observe movement quality and quickly determine whether or not the patient displays biomechanics that may predispose him or her to non-contact ACL injury.

The risk of suffering a knee injury has been reported to be higher in patients with a history of previous ACL injury than in those players without. Of patients who were 2 years removed from ACL reconstruction, there was an increased risk of 3% for tearing either the intact contralateral ACL or the reconstructed ACL graft. Likewise, poor biomechanics and neuromuscular control of the hip and knee during landing are considered to be predictors of second ACL injury in patients who have previously undergone ACL reconstruction. Therefore, the ability of a test to indentify variables that place a patient at risk for ACL injury would appear to be an important factor when determining the appropriateness of returning to sports. Based upon the requirements of the Vail Sport Test, a patient must demonstrate good control and power of the lower extremity during landing while overcoming the effects of fatigue. Therefore, it is the authors’ belief that the Vail Sport Test is a reliable tool for assessing performance during the return to sport phase of rehabilitation.

Limitations
One of the limitations of this study is the fact that the subjects were taped and then graded at a later time rather than in a real-time manner. While this system allows the grader the ability to stop and start the videotape to score movement, which may enhance reliability, it also requires a greater time commitment on the part of the grader. However, this method has been used previously and with good results.

Although the Vail Sport Test measures a patient’s ability to control the lower extremity in the sagittal and frontal plane, it does not account for rotational movements which may be involved in an ACL mechanism of injury. The inability of the Vail Sport Test to identify limitations during multiplanar movements is certainly a limitation, however, the test is believed to produce loads to the knee that are considered to be challenging to the joint and would thus give an indication of the functional abilities of the patient after ACL reconstruction.

In its present state a patient is required to score at least 46 out of 54 in order to pass the Vail Sport Test. While this score (85%) has not been validated by research, the authors’ experience and belief is that this number presents a significant challenge to those ACLR individuals when performing the test. However, continued research is required in order to provide a validated number for a passing score. Finally, a gold standard for assessing readiness to return to sports following ACL reconstruction is lacking in the literature and makes it difficult to compare to the Vail Sport Test. Even though this test battery is believed to have validity, the lack of gold standard precludes validity. In addition, the finding of reliability is not indicative of validity and thus the results should not be interpreted as the Vail Sport Test being able to assess a patient’s readiness to return to sports. While hop tests are a reliable and valid measure of performance based outcome following ACL reconstruction, the authors of the current study believe that the constructs of the Vail Sport Test represent significantly different variables and assess additional
components of muscle endurance and quality of movement. However, future research involving measurements of performance constructs after a patient has returned to sports in relation to a Vail Sport Test™ score is needed in order to validate these beliefs.

CONCLUSION
The Vail Sport Test™ is a functional tool that is reliable in assessing performance in ACLR patients during the return to sports phase of rehabilitation. When used as a component in a battery of outcome measures, this test may allow the clinician to effectively evaluate a patient's power, neuromuscular control, muscle endurance, and movement quality.

REFERENCES


APPENDIX

VAIL SPORT TEST™
Name: ___________________    Date: __________
MD: _______________  DX: ___________ Mo. S/P: ________

Total Points: ______/54 * Patient must score 46/54 on the test in order to pass

Single Leg Squat (goal: 3 minutes)

1. Knee flexion angle between 30 and 60°
   Yes (1) No (0)
2. Patient performs repetitions without dynamic knee valgus
   *knee valgus = patella falls medial to the great toe
   Yes (1) No (0)
3. Patient avoids locking knee during extension
   Yes (1) No (0)
4. Patient avoids patella extending past the toe during knee flexion
   Yes (1) No (0)
5. Patient maintains upright trunk during knee flexion
   Yes (1) No (0)

Minute 1 ________  Minute 2 ________  Minute 3 ________

Single Leg Squat Total Points: _______/15

- If patient repeats error on 3 consecutive repetitions after correction, they are not eligible to receive a point for that particular standard (within each 1 minute timeframe).

Lateral Bounding (goal: 90 seconds)

1. Knee flexion angle is 30° or greater during landing
   Yes (1) No (0)
2. Patient performs repetitions without dynamic knee valgus
   *knee valgus = patella falls medial to the great toe
   Yes (1) No (0)
3. Patient performs repetitions within landing boundaries
   Yes (1) No (0)
4. Landing phase does not exceed 1 second in duration
   Yes (1) No (0)
5. Patient maintains upright trunk during knee flexion
   Yes (1) No (0)

   1st 30 sec ________ 2nd 30 sec ________ 3rd 30 sec ________

Lateral Bounding Total Points _______/15

- If patient repeats error on 3 consecutive repetitions after correction, they are not eligible to receive a point for that particular standard (within each 30 second timeframe).

**Forward Jogging (goal: 2 minutes)**

1. Knee flexion angle between 30 and 60°
   Yes (1) No (0)

2. Patient performs repetitions within landing boundaries
   Yes (1) No (0)

3. Patient performs repetitions without dynamic knee valgus
   * knee valgus = patella falls medial to the great toe
   Yes (1) No (0)

4. Patient avoids locking knee during extension
   Yes (1) No (0)

5. Landing phase does not exceed 1 second in duration
   Yes (1) No (0)

6. Patient maintains upright trunk during knee flexion
   Yes (1) No (0)

   Minute 1 ________    Minute 2 _________

Forward Jogging Total Points ______/12

- If patient repeats error on 3 consecutive repetitions after correction, they are not eligible to receive a point for that particular standard (within each 1 minute timeframe).

**Backward Jogging (goal: 2 minutes)**

1. Knee flexion angle between 30 and 60°
   Yes (1) No (0)

2. Patient performs repetitions within landing boundaries
   Yes (1) No (0)
3. Patient performs repetitions without dynamic knee valgus  
   * knee valgus = patella falls medial to great toe  
   Yes (1) No (0)  

4. Patient avoids locking knee during extension  
   Yes (1) No (0)  

5. Landing phase does not exceed 1 second in duration  
   Yes (1) No (0)  

6. Patient maintains upright trunk during knee flexion  
   Yes (1) No (0)  

   Minute 1 ________    Minute 2 _________  

Backward Jogging Total Points _____/12  

• If patient repeats error on 3 consecutive repetitions after correction, they are not eligible to receive a point for that particular standard (within each 1 minute timeframe).  

   VIDEO LEGEND - VAIL SPORT TEST™  

   Video 1. Single Leg Squats  

   Video 2. Lateral Bounding  

   Video 3. Forward Jogging  

   Video 4. Backward Jogging
ABSTRACT

**Background:** Although both isotonic and isokinetic exercises are commonly used in the rehabilitation of patients after arthroscopic meniscectomy no studies have compared their effect on strength recovery and functional outcomes.

**Purpose:** The purpose of this study was to investigate the effects of two rehabilitation programs (isotonic and isokinetic) on muscle strength and functional performance after partial knee meniscectomy. A secondary purpose was to assess the correlation between isokinetic strength deficits and hop test performance deficits.

**Methods:** Twenty male patients who underwent arthroscopic partial meniscectomy volunteered for the study. Both isotonic and isokinetic training were performed with the same equipment thereby blinding subjects to the mode of exercise. Main outcome measures were collected on the 14th and 33rd postoperative days and included isokinetic strength of the knee extensors and flexors, functional performance (single, triple, and vertical hopping) and the Lysholm questionnaire. Multivariate and univariate analyses of variance were used to assess the effects of the independent variables on the isokinetic variables, functional tests, and Lysholm score. Pearson's correlation was used to assess the relationship between isokinetic strength deficits and functional performance deficits.

**Results:** Isokinetic measures, functional tests, and the Lysholm score all increased between initial and final assessment (p≤0.003). However, there were no group or group*time effects on any of the outcome variables (p≥0.33). Functional tests were better predictors of isokinetic deficits in the 14th compared to the 33rd postoperative day.

**Conclusion:** No differences were found in the outcomes of patients treated using an isokinetic and an isotonic protocol for rehabilitation after arthroscopic meniscectomy. More than half of patients did not meet the 90% criterion in the hop tests for safe return to sports five weeks after meniscectomy. There were correlations between the hop tests and isokinetic deficits two weeks after meniscectomy but not at the fifth week.

**Level of evidence:** 1b

**Key words:** functional tests, isokinetic, isotonic, partial meniscectomy
INTRODUCTION
The menisci of the knee are commonly injured during athletic activities that involve jump-landing and cutting tasks. Although some meniscal tears are managed conservatively, those that are symptomatic and produce locking and instability are commonly treated surgically particularly in the young, athletic patient. As a direct result of the frequency of meniscal injuries, arthroscopic meniscectomy is currently the most commonly performed orthopaedic surgery in the United States.

Arthroscopic meniscectomy may result in pain and joint effusion that lead to decreased range of motion, muscle atrophy, and decreased stability of the knee joint. A variety of rehabilitation programs have been used to treat patients recovering from arthroscopic meniscectomy and allow them to return to premorbid activity level in a safe and timely manner. Current literature on rehabilitation after meniscectomy has focused on comparing a structured rehabilitation to a home exercise group, assessing the effect of adding electrical stimulation on muscle strength, and the timing of introducing a strengthening program. Strengthening is an integral part of rehabilitation programs as the importance of strength recovery after meniscectomy has been previously demonstrated. Isotonic and isokinetic exercises are both options for strength recovery after arthroscopic meniscectomy. However, to the authors' knowledge no studies have directly compared the outcomes of these two different types of strengthening.

Functional tests that can be easily used in the clinic to assess rate of recovery such as the hop tests have long been used in patients recovering from knee surgery. Myer et al have demonstrated that hop tests are sensitive enough to detect deficits and readiness to return to sports after knee surgery when a cut-off score of 90% for the limb symmetry index (LSI) between the healthy and pathological side is used. Therefore, the main objective of this project was to compare the effectiveness of two commonly used strengthening programs (isotonic and isokinetic) by using traditional (isokinetic, Lysholm score) and more recent (hop test LSI with a 90% cut-off score) assessment measures. A secondary objective was to assess if isokinetic strength deficits correlate to hop test performance deficits. The authors hypothesized that no differences would exist between the outcomes after the two programs and that hop test deficits correlate highly with isokinetic peak torque deficits.

METHODS
Patients
This prospective randomized trial was performed in a large outpatient physical therapy clinic with a group of recreational male athletes (Table 1). Twenty-eight consecutive volunteers who presented to the clinic after arthroscopic partial meniscectomy and met the following inclusion criteria: a) surgery within 90 days from injury b) no other knee injury or pathology and c) no neuromuscular or systemic disease were offered participation in the study. Eight of those chose a home exercise program instead of physical therapy leaving 20 volunteers who were randomly allocated by computer generated random numbers to the isotonic or isokinetic group (Fig. 1) using the “matched pair” method where age and weight were the extraneous variables. Blinding of the volunteers to group allocation was maintained throughout the study. However, assessors were not blinded to group allocation.

Procedures
After completing an informed consent form that was approved by the primary author's institution, the participants were randomly assigned into the isokinetic or isotonic rehabilitation group. The common part of the rehabilitation programs started on the 4th post-operative day for both groups and consisted of five sessions of electrotherapy, joint mobilizations, proprioception exercises, isometric exercises for the quadriceps, straight leg raises, 8-10 min of stationary biking, and cryotherapy. On the 6th session (14th post-operative day) they were tested for baseline isokinetic and functional measurements and completed the Lysholm questionnaire. The Lysholm questionnaire assesses functional impairment in terms of limping, need for walking aid, instability, pain, muscle atrophy, swelling, stair climbing, and squatting. It has been validated for patients with meniscal lesions and demonstrated to be an effective measurement of disability with high reliability (ICC = 0.97). As in common clinical practice for patients after arthroscopic meniscectomy, structured rehabilitation...
started on the 4th post-operative day; however, it was deemed necessary for safety reasons to wait until the 14th day for baseline isokinetic and functional testing. After baseline testing, isokinetic or isotonic training was introduced for a total of nine sessions until the 33rd postoperative day when isokinetic and functional testing were repeated. Both isokinetic and isotonic training were performed on the Cybex Norm 770 (Medway, MA) and therefore subjects were blinded to treatment group allocation. The isokinetic training protocol started with a session of two sets of 10 repetitions at 150, 180 and 210°/sec on the 15th postoperative day and gradually progressed to a session of three sets of 15 at 180, 210 and 240°/sec, two sets of 10 at 120 and 150°/sec and two sets of six at 60 and 90°/sec on the 30th postoperative day. The protocol was created based upon the clinical experience of the authors. Similarly, each session of the isotonic training program started with establishing the actual one repetition maximum (1 RM). The first session consisted of two sets of 10 repetitions at 60, 65 and 70% of one repetition maximum (1 RM) and progressed to a session of two sets of 15 at 60, 65 and 70% of 1 RM, two sets of 10 at 75 and 80% of 1 RM, and one set of six at 85 and 90% of 1 RM on the 30th postoperative day. It has been previously demonstrated that performance of the healthy leg after meniscectomy changes over time, therefore we selected to test both lower extremities at each evaluation session to

Figure 1. CONSORT flow diagram.
allow for normalization. All patients were instructed to inform the tester if pain was experienced in either lower extremity during testing.

The outcome measures consisted of the Lysholm questionnaire, isokinetic, and functional testing. Prior to the isokinetic test, subjects warmed up by riding a stationary bike for 8 min at 65 rpm and 0.8 Watt and by self-stretching the quadriceps and hamstrings of both lower extremities from the standing position. Placement of subjects was standardized by placing their hip at 90°, their trunk and upper thigh was stabilized by belts, and the distal end of the moving arm was attached immediately superior to the lateral malleolus. The axis of the dynamometer was aligned with the axis of the knee and allowed a range of motion from 0° to 105° of flexion. Gravity correction was applied to allow accurate comparisons between subjects. All subjects attended two practice sessions on the isokinetic device in the two days preceding the initial test in order to minimize any learning effects. The protocol included three submaximal extension/flexion concentric trials followed by three maximal trials with the dynamometer set at 60°/sec. After a 30 sec break three submaximal and three maximal trials at 180°/sec were performed. The maximum torque for knee extension and flexion in each angular velocity (average of three trials) was calculated.

Three functional tests were also performed: a) the single leg hop is a unilateral maximal hop for distance with the arms behind the back and has been shown to have high reliability (ICC = 0.96), b) the triple hop as described by Risberg et al consists of three hops for distance starting with a bilateral jump-unilateral landing, followed by a unilateral hop and landing, and ending by a unilateral hop to a bilateral landing. It has also been shown to be highly reliable (ICC = 0.92). and c) the modified unilateral vertical hop test for height was measured with a tape measure secured around the subject's belt who was then instructed to jump vertically and maximally while keeping his arms by his side. Three trials were performed for each one of the hop tests and the best trial was used for the statistical analysis. The non-operated leg was tested first followed by the operated leg for all measurements. The limb symmetry index (LSI) was calculated for all isokinetic and functional measurements as per the following formula: value of involved leg/value of uninvolved leg *100. With this method each value is presented as a proportional deficit (percentage) of the operated compared to the non-operated leg.

Statistical Analysis
The effect of the independent variables time (initial measurement vs. final measurement) and group (isokinetic vs. isotonic) on the Lysholm score was evaluated with an analysis of variance test (ANOVA). The effects of the independent variables on the isokinetic variables and functional tests were evaluated with the use of two separate multivariate analysis of variance (MANOVA) followed by univariate tests when statistically significant differences were found. The α level was set a priori at 0.05. Post-hoc power analysis revealed that for an α level of 0.05 and power of 80% the current study was powered to detect effect sizes that were medium or higher. For the second objective of the study Pearson’s correlation coefficients were calculated for the LSI of each of the three hop tests and the LSIs for each of the four isokinetic measurements at both assessment time points. Correlations with R² lower than 0.1 were defined as “none”, higher than 0.1 and lower than 0.3 as “small”, higher than 0.3 and lower than 0.5 as “medium”, and higher than 0.5 as “large.”

RESULTS
Descriptive statistics for the characteristics of the subjects are presented in Table 1. Subjects in both groups had similar mean ages (Isokinetic 28.0 yrs and Isotonic 28.1 years), had similar weights (Isokinetic 77.9 kg, Isotonic 78.7 kg), and were similarly represented by which leg was operated on (Isokinetic group 5 right, 5 left; Isotonic group 4 right, 6 left). There was minimal variation between groups regarding surgical treatment for medial, lateral, or both menisci being treated.

Descriptive data regarding the dependent variables were grouped into three categories: a) the Lysholm score b) isokinetic variables (peak torque of knee extensors and flexors at 60°/sec and 180°/sec) and c) functional tests (single, triple and vertical hop tests), and are reported in Table 2.

The statistical tests were performed on the Lysholm scores and the LSI of the isokinetic and hop test variables. The results of the ANOVA revealed that time (p < 0.001) but not group or the interaction of group*time...
(p≥0.55) had a significant effect on the Lysholm score. The Lysholm score increased from 75% at the initial measurement to 92% at the final measurement (average for both groups). However, it is important to note that 33 days after surgery 30% of patients had Lysholm scores below 90% which is the threshold for safe return to sports.

The MANOVAs revealed that time (p≤0.001) but not group or the interaction of group*time (p≥0.33) had a significant effect on the LSI of the isokinetic and hop test variables. Univariate tests revealed that for both groups between the initial and final measurements, the LSI for peak flexion torque at 60°/sec increased from 80 to 92%, for peak flexion torque at 180°/sec increased from 84 to 97%, for peak extension torque at 60°/sec increased from 69 to 86%, and for peak extension torque at 180°/sec increased from 77 to 88% (p≤0.003). Additionally, the LSI for the single hop increased from 78 to 92%, for the triple hop from 88 to 95%, and for the vertical hop from 74 to 92% (p<0.001). Only 45% of patients had ≥90% LSI for all three hop tests at final assessment.

Linear regression Pearson’s correlations revealed in the 14th post-operative day there were significant

<table>
<thead>
<tr>
<th><strong>Table 1. Characteristics of volunteers</strong></th>
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<tbody>
<tr>
<td>Age in yrs. (SD)</td>
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<td></td>
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<tr>
<td>Weight in kg (SD)</td>
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<tr>
<td>Operated leg (right/left)</td>
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<td>Meniscectomy (medial/lateral/both)</td>
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<tr>
<th><strong>Table 2. Means (standard deviations) and 95% confidence intervals for the outcome variables.</strong></th>
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<tr>
<td>Isokinetic group</td>
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<tr>
<td>14th post-operative day</td>
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<tr>
<td>Lysholm (score 0-100, 100= best)</td>
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<tr>
<td>76(7), 70-81</td>
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<tr>
<td>94(5), 90-98</td>
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<tr>
<td>91(8), 85-97</td>
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<tr>
<td>Knee flexion at 60°/sec (Nm/kg)</td>
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<tr>
<td>1.17(0.4), 0.89-1.45</td>
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<td>1.40(0.4), 1.08-1.72</td>
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<td>1.14 (0.4), 0.85-1.43</td>
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<tr>
<td>1.46(0.4), 1.19-1.73</td>
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<tr>
<td>Knee flexion at 180°/sec (Nm/kg)</td>
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<tr>
<td>0.90(0.4), 0.64-1.15</td>
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<tr>
<td>1.15(0.3), 0.90-1.40</td>
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<tr>
<td>0.89(0.2), 0.73-1.05</td>
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<tr>
<td>1.17(0.3), 0.99-1.35</td>
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<tr>
<td>Knee extension at 60°/sec (Nm/kg)</td>
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<tr>
<td>1.80(0.5), 1.41-2.17</td>
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<tr>
<td>2.22(0.6), 1.81-2.62</td>
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<tr>
<td>1.90(0.5), 1.53-2.29</td>
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<tr>
<td>2.27(0.4), 1.95-2.58</td>
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<tr>
<td>Knee extension at 180°/sec (Nm/kg)</td>
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<tr>
<td>1.36(0.4), 1.04-1.68</td>
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<tr>
<td>1.58(0.4), 1.27-1.88</td>
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<tr>
<td>1.33(0.3), 1.11-1.55</td>
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<tr>
<td>1.64(0.3), 1.43-1.85</td>
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<tr>
<td>Single hop (cm)</td>
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<tr>
<td>112(31), 90-135</td>
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<tr>
<td>146(32), 123-169</td>
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<tr>
<td>123(30), 101-145</td>
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<tr>
<td>149(32), 126-172</td>
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<td>Triple hop (cm)</td>
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<tr>
<td>397(118), 312-481</td>
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<tr>
<td>487(85), 426-548</td>
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<tr>
<td>429(94), 362-496</td>
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<tr>
<td>481(72), 429-533</td>
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<tr>
<td>Vertical hop (cm)</td>
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<tr>
<td>18(5), 15-22</td>
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<td>26(8), 20-32</td>
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<tr>
<td>17(6), 13-21</td>
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<td>21(4), 18-24</td>
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<tr>
<td>Single hop LSI (%)</td>
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<tr>
<td>76(15), 65-87</td>
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<tr>
<td>90(10), 83-98</td>
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<tr>
<td>80(11), 72-87</td>
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<tr>
<td>93(6), 88-97</td>
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<tr>
<td>Triple hop LSI (%)</td>
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<tr>
<td>86(10), 79-93</td>
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<td>95(5), 91-99</td>
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<tr>
<td>90(6), 85-95</td>
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<tr>
<td>96(4), 92-99</td>
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<tr>
<td>Vertical hop LSI (%)</td>
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<tr>
<td>72(13), 63-82</td>
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<tr>
<td>92(10), 84-99</td>
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<tr>
<td>76(13), 66-85</td>
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| LSI= limb symmetry index; Note: Isokinetic and hop variables are for the involved leg
correlations between isokinetic LSI and the single and vertical hop LSI while in the 33rd post-operative day there were no significant correlations (Table 3).

**DISCUSSION**

One of the main findings of this project is that there was no difference in outcome measures between patients who followed either an isokinetic or an isotonnic rehabilitation protocol. Since no difference is found between the two programs, physical therapists should consider using either type or incorporating a combination of both types of exercises in the rehabilitation of patients who had arthroscopic meniscectomy. In practical terms, it probably also means that the absence of an isokinetic device in physical therapy clinics does not compromise the recovery of patients.

Although quick recovery was observed in both groups, it needs to be highlighted that more than half of patients were still below the 90% limb symmetry cut-off score in the functional tests that is considered safe for return to sports. Pressure is commonly placed on athletes to return to sports very quickly after knee arthroscopy, however, based on the current results it seems that less than half of them are ready for a safe return to sports 33 days after surgery. Additionally, the present study extends recent findings in anterior cruciate ligament (ACL) recovery research to arthroscopic meniscectomy patients showing that the unilateral hop tests are more sensitive in detecting deficits than the Lysholm score, that classified 70% of this group of patients as normal.

It needs to be emphasized, however, that the rehabilitation program in both groups were rather accelerated. Gapeyeva et al. utilized a much more conservative program that resulted in isokinetic knee extension deficits that were 2-3 times higher than those found in the present study. Although the long-term effects of the accelerated rehabilitation program on patients after arthroscopic meniscectomy cannot be evaluated by this study, it is encouraging that the authors did not observe any adverse effects of either program on pain, edema, or range of motion. St. Pierre et al. suggested that introducing isokinetic training at 2 weeks after surgery does not produce better outcomes compared to introducing the same program 6 weeks after surgery. As in the current study, St. Pierre et al. found no increase in adverse effects in the accelerated rehabilitation group. The findings of the current study are consistent with previous research that found that introducing an accelerated strengthening program early after surgery results in reasonable strength recovery within a month.

Although isokinetic devices do not appear to be a necessary rehabilitation tool for a good outcome after arthroscopic meniscectomy their role as assessment tools may not be completely replaced by functional tests in those patients in need of an accurate assessment of strength deficit. The results of the current study demonstrate that in the 2nd week after surgery there are strong correlations between strength deficits and hop performance but by the 5th week of the rehabilitation program the correlations diminish. Although, to the authors’ knowledge, this is the first study to examine the correlation between functional hop tests and isokinetic deficits in patients who underwent arthroscopic meniscectomy, an abundance of similar studies exists for healthy subjects or patients who underwent ACL reconstruction. The results vary with some authors reporting high correlations while others reported low correlations. It appears that the correlations between the functional hop and isokinetic measurements depend not only on the population and the methodology but also on the time that has elapsed after the surgical procedure. It is possible that as patients develop more equal side-to-side performance, functional tests become less sensitive in detecting strength deficits.

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**Table 3.** P-values (coefficients) for the correlation between the lower limb symmetry indices of the isokinetic and hop tests.

<table>
<thead>
<tr>
<th></th>
<th>14th post-operative day</th>
<th>33rd post-operative day</th>
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<tbody>
<tr>
<td></td>
<td>Single hop</td>
<td>Triple hop</td>
</tr>
<tr>
<td>Knee flexion 60°/sec</td>
<td>0.017 (0.42)*</td>
<td>0.310 (0.20)</td>
</tr>
<tr>
<td>Knee flexion 180°/sec</td>
<td>0.001 (0.61)*</td>
<td>0.442 (0.15)</td>
</tr>
<tr>
<td>Knee extension 60°/sec</td>
<td>0.138 (0.13)</td>
<td>0.826 (-0.04)</td>
</tr>
<tr>
<td>Knee extension 180°/sec</td>
<td>0.021 (0.43)*</td>
<td>0.949 (0.01)</td>
</tr>
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*Statistically significant at p≤0.05
Limitations
Several limitations are acknowledged in this study. The sample size of only 10 patients per group may have increased the possibility of having insufficient power to detect differences between the groups. However, all measurements revealed remarkably similar mean values between the two groups suggesting that the lack of statistically significant differences is due to lack of effect and not due to lack of power. The current study did not discriminate between the surgeons who performed the procedure. Five surgeons performed all 20 meniscectomies, thereby making the sample less homogeneous. The authors acknowledge that the current results cannot be extrapolated to female patients as all patients in this sample were males. Finally, the current sample consisted of consecutive patients presenting at a large outpatient rehabilitation center and, therefore, may not be representative of the general population of patients who undergo arthroscopic meniscectomy.

CONCLUSIONS
No differences were found in the strength and functional testing outcomes of patients who had undergone arthroscopic meniscectomy when rehabilitated using an isokinetic and an isotonic protocol. More than half of patients did not meet the 90% criterion in the hop tests for safe return to sports five weeks after meniscectomy. Additional skilled rehabilitation may be necessary for athletes to safely meet return to sports criteria. There were correlations between the hop tests and isokinetic deficits two weeks after meniscectomy but they were diminished by the fifth week.

REFERENCES


ABSTRACT

Background: Alterations in scapular and glenohumeral kinematics in patients with shoulder dysfunction have been recognized by this study's authors and described in multiple other studies available in the literature. A reliability study was developed to assess a new technique for measuring scapulohumeral kinematics. Previous scapular position measuring techniques may require expensive equipment which decreases clinical utility. Other techniques require identification of multiple anatomic landmarks that may decrease accuracy, precision, and reliability.

Methods: A sample of asymptomatic controls and symptomatic study subjects were recruited. Each subject had markers placed on each acromion and stood at a standardized distance in front of a light. The shadow projected from the acromial marker onto a standardized, data collection board was measured during the resting, flexion, and scaption positions for bilateral shoulders. The horizontal and vertical translations of the shadows were measured compared to the resting point for both flexion and scaption.

Results: The scapula translated superiorly and medially during both flexion and scaption movements in all subjects and controls. There was good inter-rater reliability for measuring scapular translation with scaption (ICC = 0.81) and moderate reliability for measuring scapular translation with flexion (ICC = 0.62). There was increased superior and medial scapular translation in the subjects with flexion (p = 0.004 and p = 0.002) and scaption (p = 0.01 and p = 0.007) in the symptomatic shoulder compared to the asymptomatic shoulder. Superior scapular translation with flexion (p = 0.0003) and scaption (p = 0.006) and medial scapular translation with flexion (p < 0.0001) and scaption (p < 0.0001) was greater in the symptomatic subjects compared to controls.

Conclusions: The scapula translates both superiorly and medially with flexion and scaption in asymptomatic and symptomatic subjects. After shoulder surgery, patients have increased superior and medial translation of the scapula compared to 1) their asymptomatic shoulder and 2) an asymptomatic control group. The current technique has good inter-rater reliability (ICC = 0.81) when measuring scaption and moderate reliability when measuring flexion (ICC = 0.62).

Level of Evidence: III Diagnostic Case-Control Study

Key terms: Measurement of scapular position, scapular kinematics, scapular dyskinesis

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Institutional Review Board Approval was obtained: Avera McKennan Hospital # 2008.009
BACKGROUND
It has been noted anecdotally by the authors of this manuscript that when patients with shoulder pain and dysfunction attempt glenohumeral flexion or scaption, there is increased trapezius activation and subsequent scapulohumeral elevation.¹ We have noted that with this scapulohumeral substitution, the acromial aspect of the scapula appears to translate both superiorly and medially. We have recognized these alterations in scapulohumeral kinematics in both nonoperatively treated patients with shoulder dysfunction and also in patients in the early postoperative period after shoulder surgery. Other authors have also identified increased superior translation of the scapula²-⁴, increased lateral rotation of the scapula⁵-⁶, and a more upwardly rotated scapula⁷ in patients with symptomatic shoulders due to a variety of pathologies. It is difficult to determine if this scapulohumeral substitution is a negative consequence of shoulder dysfunction, or an adaptive process that benefits the patient with shoulder dysfunction. Unfortunately, previously described methods of measuring scapular movements require expensive equipment²,⁵,⁷-¹⁵ or require identification of multiple anatomic landmarks that could cause a decrease in precision, accuracy, and reliability of measurements.²,¹⁶-¹⁹ In an attempt to further investigate whether scapulohumeral substitution in patients with shoulder dysfunction is an adaptive process or a negative consequence, the authors developed a new technique for measuring scapulohumeral position. This technique can be readily performed in the physical therapist’s or orthopaedist’s clinic and does not require expensive equipment.

The purpose of this study was to investigate the reliability of a novel technique for measuring scapulohumeral translation. The initial hypotheses of this study was that this novel technique for measuring scapulohumeral translation will: 1) demonstrate at least moderate inter-rater reliability in measuring scapular translation during glenohumeral flexion and scaption. Additionally, the authors hypothesized that the acromial aspect of the scapula will translate superiorly and medially during shoulder flexion and elevation in the scapular plane (scaption). Lastly, the authors hypothesized that: 1) there would be no difference in scapular translation between the dominant and non-dominant shoulders in asymptomatic control patients, 2) there would be a difference in scapular translation between the symptomatic shoulder and the asymptomatic shoulder in subjects with unilateral shoulder dysfunction, and 3) there would be a difference in scapular translation between subjects with postoperative shoulder dysfunction and asymptomatic controls.

METHODS
After institutional review board approval was obtained, the inter-rater reliability of this novel technique was examined by recruiting 10 asymptomatic individuals (ages 25-50) from the staff of the rehabilitation department of the authors’ institution. Inclusion for subjects in the reliability pilot study required that these individuals had no prior history of shoulder pain or dysfunction, and all had symmetric range of motion of bilateral shoulders in both the scaption and flexion motions. Three physical therapists (RO, DS, JE), each with at least 13 years of experience treating musculoskeletal conditions about the shoulder complex, independently assessed each study participant using this novel technique for measuring scapular translation. Each investigator was blinded to the other investigators’ ratings. Inter-rater reliability was determined for scapulohumeral movement in the sagittal plane (superior/inferior) and the coronal plane (medial/lateral) for both glenohumeral flexion and scaption.

To determine the amount of scapular translation that occurs in asymptomatic individuals during glenohumeral flexion and scaption, a second cohort of 18 asymptomatic individuals (mean age 37; range 26-50) were recruited from the staff of the rehabilitation department of the authors’ institution. Inclusion in this control group required that these individuals had no prior history of shoulder pain and dysfunction, and all had symmetric range of motion of bilateral shoulders in both the scaption and flexion motions. This cohort is hereafter referred to as the control group.

A third cohort of subjects was recruited to examine patients with shoulder dysfunction. This cohort included 13 patients in postoperative recovery from shoulder surgery (mean age 56; range 44-75) that were recruited from the physical therapy clinics of the authors’ institution [Table 1]. These patients had symptoms of pain and weakness that are typical of postoperative patients in the various phases of rehabilitation after shoulder surgery. Exclusion criteria included patients with bilateral shoulder symptoms or cervical spine pathology.
All subjects provided their informed consent for participation within this study. The participants in both the control and investigational cohorts were examined using this novel technique to examine scapulohumeral translation by a single physical therapist (RO) with 32 years’ experience treating conditions of the shoulder complex. Side-to-side differences among the cohorts and differences between the cohorts were examined to determine if symptoms of shoulder pain and dysfunction affected the degree of scapulohumeral translation that occurs with glenohumeral flexion and scaption.

**Measurement Technique**

Each subject stood on a 55 cm long adhesive tape marker located on the floor parallel to and centered at 15 cm from a wall containing a specially formulated board.
Each subject was properly disrobed to permit unrestricted motion of both upper extremities (women were asked to remove their bra if bra straps crossed the shoulder - a gown was utilized to provide adequate coverage for privacy) and permit visibility of the markers during movement of the shoulders. Each subject was instructed to center themselves directly above the center point of the tape with the feet spaced comfortably apart placing equal weight on each foot and facing away from the board toward the high intensity light. Subjects were instructed to remain still during the remainder of the session as the researchers placed marks on the board.

Prior to measurement, each subject was instructed to shrug their shoulders three to four times and then relax. Once the subject was relaxed and standing upright, the light was turned on and a colored pencil was used to place a single point mark at the highest point of the shadow cast by each retroreflective marker onto the board while the subject was at rest. The light was left on for the remainder of the session. Patients were then instructed to perform forward flexion to 90° with thumbs pointing toward the ceiling. The subject performed this motion three times and on the last movement the subject was advised to hold the position while marks were placed on the board with a different colored marker using the same procedure noted above. The position of 90° was visually estimated when the upper arm was parallel to the floor surface. Subjects were then instructed to perform elevation in the plane of the scapula to 90° with the thumbs pointing toward the ceiling. The subject again performed this motion three times and on the last movement the subject was advised to hold the position while marks were placed on the board with a different colored marker using the same procedure noted above.

At the completion of the measuring phase there were three colored marks (dots) for each shoulder on the recording surface [Figure 5]. In order to measure the amount and direction of scapular translation in the superior/inferior plane, a bullet level was used to draw a horizontal line through the location of each “dot” that was recorded for each side (three colored dots on each side). The level line was extended so it intersected with one of the vertical measurement scales. The vertical numerical values...
for the resting, flexion and scaption positions were recorded. This number was recorded to the nearest millimeter. In order to measure the amount and direction of scapular translation in the medial/lateral plane, a bullet level was used to draw a plumb (vertical) line through the location of each colored mark (dot). The distance between the vertical (plumb) lines drawn from each colored mark was then measured with a standard non-elastic fiber tape graduated in millimeters and the result was recorded on a data collection sheet. The distance from the resting vertical line to the flexion vertical line and from the resting vertical line to the scaption vertical line was measured and the result recorded on the data collection sheet [Figure 6].

STATISTICAL ANALYSIS

Interrater reliability coefficients were calculated as random effects (i.e., conservatively assuming that the raters are a random subset of all possible raters) intraclass correlations using SAS® software and the method described by Shrout and Fleiss22 and Hamer.23 Fischer’s test was used to determine whether statistically significant differences existed between reliability for the scaption and flexion measurements.24 Tests for normality were performed using the Shapiro-Wilk test. Differences between groups was determined by two-tailed t-tests using Excel 2003 (Microsoft, Redmond, WA). Alpha level for significance was preselected at p<.05.

RESULTS

Inter-rater Reliability for Determining Scapular Translation

The inter-rater reliability using this technique for measuring the amount of superior and medial translation of the scapula was determined to have moderate to good (ICC’s ranging from 0.753-0.807) agreement20 [Table 2] as determined in the reliability study. When all measurements were examined collectively, scaption

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**Table 2. Inter-rater reliability of scapular translation measurements.**

<table>
<thead>
<tr>
<th>Test Measurement Position</th>
<th>ICC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resting Position</td>
<td>0.996</td>
</tr>
<tr>
<td>Vertical Flexion Translation</td>
<td>0.608</td>
</tr>
<tr>
<td>Vertical Scaption Translation</td>
<td>0.704</td>
</tr>
<tr>
<td>Horizontal Flexion Translation</td>
<td>0.697</td>
</tr>
<tr>
<td>Horizontal Scaption Translation</td>
<td>0.723</td>
</tr>
<tr>
<td>All Horizontal Measurements</td>
<td>0.712</td>
</tr>
<tr>
<td>All Vertical Measurements</td>
<td>0.753</td>
</tr>
<tr>
<td>All Flexion Measurements</td>
<td>0.616</td>
</tr>
<tr>
<td>All Scaption Measurements</td>
<td>0.807</td>
</tr>
</tbody>
</table>

---

**Figure 5.** The shadow projected by the light was marked at its apex for the resting position (R), the flexion position (F), and the scaption position (S).

**Figure 6.** In order to measure the amount and direction of scapular translation that occurred with flexion and scaption, plumb lines were drawn in both the horizontal and vertical directions from the resting (R), flexion (F), and scaption (S) positions. The amount of superior and medial translation for flexion and scaption compared to the resting measurements were measured.
measurements (ICC = 0.807) were significantly more reliable than flexion measurements (ICC = 0.616) 
(z = 11.82, p < .0001).

Direction of Scapular Translation
All controls demonstrated: 1) superior scapular translation (elevation) with scaption (2.6±1.3 cm) and 2) medial scapular translation with both flexion 
(2.4±0.9 cm) and scaption (2.8±1.1 cm). For shoulder flexion, 16 of 18 controls demonstrated superior scapular translation for both dominant and non-dominant shoulders (1.6±1.2 cm). In the superior/inferior direction, one patient demonstrated no scapular translation with dominant shoulder flexion and one patient showed no scapular translation with non-dominant shoulder flexion. None of the controls demonstrated lateral or inferior scapular translation. The scaption measurements within the control population were determined to be normally distributed (p = .80).

In the post-operative subjects, all symptomatic shoulders demonstrated both superior scapular translation with both flexion (4.1±1.9 cm) and scaption (4.7±2.2 cm) and medial scapular translation with both flexion (5.4±1.6 cm) and scaption (6.2±2.0 cm) [Figure 7a and 7b]. Of these subjects' asymptomatic shoulders, 11 of 13 demonstrated both superior and medial scapular translation with both flexion and scaption. One subject's asymptomatic shoulder showed no scapular translation with shoulder flexion (in the superior/inferior plane) and one subject's asymptomatic shoulder showed no scapular translation (in the medial/lateral plane) with shoulder flexion. No post-operative subjects demonstrated lateral or inferior scapular translation.

Difference in scapular translation between dominant and non-dominant shoulders in the control group
The control group was used to determine if a difference existed in the degree of scapulohumeral movement between dominant and non-dominant shoulders. There were no statistically significant differences found in relation to shoulder dominance for the degree of superior scapular translation with flexion (p = 0.84) and scaption (p = 0.89) or medial scapular translation with flexion (p = 0.68) and scaption (p = 0.07) [Table 3].

<table>
<thead>
<tr>
<th></th>
<th>Dominant</th>
<th>Non-Dominant</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion Superior Translation</td>
<td>1.6 ± 1.2 cm</td>
<td>1.5 ± 1.3 cm</td>
<td>0.84</td>
</tr>
<tr>
<td>Scaption Superior Translation</td>
<td>2.7 ± 1.3 cm</td>
<td>2.6 ± 1.2 cm</td>
<td>0.89</td>
</tr>
<tr>
<td>Flexion Medial Translation</td>
<td>2.4 ± 1.0 cm</td>
<td>2.3 ± 0.8 cm</td>
<td>0.68</td>
</tr>
<tr>
<td>Scaption Medial Translation</td>
<td>3.1 ± 1.3 cm</td>
<td>2.4 ± 0.9 cm</td>
<td>0.07</td>
</tr>
</tbody>
</table>
Comparison of Scapular Translation between the Symptomatic Shoulder and the Asymptomatic Shoulder in the Post-Operative Subjects

In the post-operative subjects, there was a statistically significant difference between the symptomatic shoulder and the asymptomatic shoulder regarding superior scapular translation with flexion (p = 0.004) and scaption (p = 0.01) and the degree of medial scapular translation with flexion (p = 0.002) and scaption (p = 0.007). However, there was no significant difference in the static resting position of the symptomatic and asymptomatic shoulder [Table 4].

Comparison of Scapular Translation between the Control Group and the Post-Operative Subjects

Since there was no statistical difference between dominant and non-dominant shoulders in the control group, the two were combined to compare the scapular translation of the control group to that of the symptomatic shoulder subjects. A statistically significant difference was found between the control group and the subjects for the degree of superior scapular translation with flexion (p = 0.0003) and scaption (p = 0.006) and the degree of medial scapular translation with flexion (p = 0.0001) and scaption (p < 0.0001) [Table 5].

Comparison of Side-to-side Differences between the Control and Post-Operative Subjects

For flexion measurements, the side-to-side differences were greater in the post-operative subjects for both superior translation (1.88 ± 1.60 vs. 0.68 ± 0.47 cm; p = 0.02) and medial translation (2.79 ± 2.50 vs. 1.27 ± 0.83 cm; p = 0.05) compared to the control group. For scaption measurements, the side-to-side differences were also greater in the post-operative subjects for both superior translation (2.28 ± 2.16 vs. 0.71 ± 0.72 cm; p = 0.02) and medial translation (3.22 ± 2.54 vs. 1.34 ± 1.07; p = 0.07) compared to the control group.

Using this data, a side-to-side difference of 2 centimeters was shown to have a sensitivity of 0.55 and a specificity of 0.97 in demonstrating abnormal or pathologic scapular elevation with scaption.

DISCUSSION

The initial purpose of this study was to develop and investigate the reliability of a novel technique for measuring scapulohumeral translation. The hypotheses of this study were supported by the data and statistical interpretation.

This study demonstrates that the current technique has moderate to good inter-rater reliability in measuring both the superior and medial translation of the acromial

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**Table 4. Scapular translation between the symptomatic shoulder and the asymptomatic shoulder in the post-operative subjects.**

<table>
<thead>
<tr>
<th></th>
<th>Symptomatic Shoulder</th>
<th>Asymptomatic Shoulder</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resting Value</td>
<td>52.3 ± 7.9 cm</td>
<td>52.1 ± 7.2 cm</td>
<td>0.953</td>
</tr>
<tr>
<td>Flexion Superior Translation</td>
<td>4.14 ± 1.87 cm</td>
<td>2.40 ± 1.29 cm</td>
<td>0.004</td>
</tr>
<tr>
<td>Scaption Superior Translation</td>
<td>4.72 ± 2.24 cm</td>
<td>2.69 ± 1.44 cm</td>
<td>0.01</td>
</tr>
<tr>
<td>Flexion Medial Translation</td>
<td>5.36 ± 1.62 cm</td>
<td>2.58 ± 1.53 cm</td>
<td>0.002</td>
</tr>
<tr>
<td>Scaption Medial Translation</td>
<td>6.24 ± 1.98 cm</td>
<td>3.48 ± 1.76 cm</td>
<td>0.007</td>
</tr>
</tbody>
</table>

**Table 5. Scapular translation between the controls and the post-operative subjects.**

<table>
<thead>
<tr>
<th></th>
<th>Controls</th>
<th>Post- Op Subjects</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion Superior Translation</td>
<td>1.6 ± 1.2 cm</td>
<td>4.14 ± 1.87 cm</td>
<td>0.0003</td>
</tr>
<tr>
<td>Scaption Superior Translation</td>
<td>2.6 ± 1.3 cm</td>
<td>4.72 ± 2.24 cm</td>
<td>0.006</td>
</tr>
<tr>
<td>Flexion Medial Translation</td>
<td>2.4 ± 0.9 cm</td>
<td>5.36 ± 1.62 cm</td>
<td>0.00001</td>
</tr>
<tr>
<td>Scaption Medial Translation</td>
<td>2.8 ± 1.1 cm</td>
<td>6.24 ± 1.98 cm</td>
<td>0.00003</td>
</tr>
</tbody>
</table>
aspect of the scapula that occurs with glenohumeral flexion and scaption in asymptomatic patients. Since scaption measurements were normally distributed in the control population and appear to be more reliable compared to flexion measurements, the authors of the current study recommend the use of scaption measurements over flexion measurements for assessment of scapulohumeral translation.

Patients assessed during their post-operative recovery after shoulder surgery demonstrated significantly increased scapular superior and medial translation compared to: 1) their asymptomatic shoulder and 2) an asymptomatic control group. In order to determine a reference measurement that may be used in future studies or clinical scenarios to demonstrate an abnormal amount of vertical translation that occurs with scaption in symptomatic subjects, the side-to-side difference was examined. The side-to-side difference in the control group was $0.71 \pm 0.72$ cm and the difference in the postoperative subjects was $2.27 \pm 2.16$ cm. Using a side-to-side difference of 2 centimeters as the reference measurement for pathological translation, the authors propose the use of a value that is close to two standard deviations greater than the mean side-to-side difference of the control group. This value also approximates the mean side-to-side difference of the postoperative subjects. Therefore, using a side-to-side difference of 2 centimeters as the reference value to demonstrate abnormal or pathologic scapular elevation with scaption reveals a sensitivity of 0.55 and a specificity of 0.97. These values support the use of a side-to-side difference of 2 centimeters as an appropriate clinical screening tool to examine for pathologic vertical scapular translation with scaption, when using this technique.

Although this manuscript describes a novel technique that demonstrates that the scapula translates medially and superiorly with glenohumeral flexion and scaption, it is not the first technique that documents scapular elevation. There have been several different techniques described for measuring scapular kinematics. Several of these techniques are able to analyze scapular kinematics in three dimensions, whereas the currently described technique is only able to assess scapular kinematics in two dimensions. However, the advantages of the current technique is that it does not require expensive equipment such as the electromagnetic movement sensors, digital inclinometers, electromyography, projectors and microcomputers, or radiography. In addition, this new technique does not require identification of multiple anatomic landmarks that could cause a decrease in precision, accuracy, and reliability of measurements. Therefore, this method has been shown to be both reliable and easily reproducible in the physical therapist’s or orthopaedist’s clinic.

In addition to the inability of this technique to determine three dimensional scapular position, other potential limitations of this study include: 1) small number of patients included in the study groups and 2) the heterogeneity of the patients included in the subject group. Additional studies should be expanded to include larger numbers of subjects as well as a more diverse subject pool by diagnosis (including those without operative diagnoses), age, and chronicity of shoulder dysfunction.

The findings of this current study are similar to several previously published findings. Lukasiewicz et al. also demonstrated that the scapula moved superiorly and medially with increasing arm elevation in the scapular plane. In addition, they showed that the patients with impingement demonstrated significantly greater superior translation of the scapula during arm elevation when compared to controls. However, unlike the current study, differences between the asymptomatic and symptomatic sides of patients with impingement were not significantly different. Babyar also found increased scapular elevation in symptomatic individuals although they suggested that scapular elevation could be influenced by verbal instruction and practice. Using Moiré topographical techniques, Warner et al. suggested that in patients with impingement the symptomatic shoulder is higher than the contralateral, asymptomatic side. Lastly, similar to the current findings, no side to side differences were demonstrated in scapular elevation during glenohumeral abduction in asymptomatic patients.

Other studies have examined the concept of scapular substitution in patients with shoulder dysfunction. Utilizing a three dimensions electromagnetic motion-tracking system, Rundquist demonstrated that subjects with symptomatic shoulders exhibited more upwardly rotated scapulae when compared to the
asymptomatic side. Fayad et al. also utilized an electromagnetic motion-tracking system to demonstrate increased scapular lateral rotation in patients with glenohumeral osteoarthritis and adhesive capsulitis. In the review of the literature for the current study, only one other study was identified that assessed postoperative scapular kinematics. Using an electromagnetic tracking device, increased lateral scapular rotation was identified in patients undergoing reverse shoulder arthroplasty when compared to those with healthy shoulders.

Evidence of increased upper trapezius activation, combined with increased superior translation of the scapula, has been demonstrated in persons with shoulder pathology. Electromyographic studies have demonstrated an increased activation in the upper trapezius during shoulder elevation tasks in patients with symptomatic shoulders compared to asymptomatic patients. Patients with impingement had more upper and lower trapezius muscle activation compared with asymptomatic subjects. Ludeweg et al. suggested that excessive upper trapezius activation and imbalances of force production between the serratus anterior and the upper trapezius can result in a shoulder-shrugging motion with arm elevation causing increased superior translation of the scapula and less efficient upward rotation and reduced posterior tipping of the acromion.

Rundquist suggested that scapular substitution may be a compensatory mechanism that allows a patient to continue to function in the presence of shoulder symptoms. Fayad et al. suggested that these alterations in scapular kinematics may help patients by providing a more effective scapular position for arm elevation. Negative consequences of scapular substitution and altered flexion and scaption patterns may include subacromial impingement, rotator cuff or biceps tendon irritation and subsequent tendinopathy, and altered acromioclavicular joint forces which may predispose to degenerative changes. In addition, the authors of the current study believe that altered scapular kinematics may be associated with a higher incidence of neck pain related to the trapezius.

As shoulder rehabilitation programs evolve, comparative testing of different rehabilitation approaches is needed. To improve our understanding of the mechanisms by which shoulder function is enhanced through rehabilitation, outcome assessments should address kinematic and muscle activity alterations as well as symptoms and functional status. Further research into the association between scapular substitution and the presence of pain and weakness is warranted in both operatively and nonoperatively treated patients. Further studies are needed to determine: 1) if postoperative scapulohumeral kinematic alterations can be modified and 2) what rehabilitative techniques are optimal for normalizing these alterations.

**CONCLUSION**

The novel technique for measuring scapulohumeral translation described herein demonstrated moderate to good reliability with scaption and flexion, respectively. It is easily reproducible in the clinic and does not require expensive equipment. With both scaption and flexion, the acromial aspect of the scapula tends to translate medially and superiorly and is representative of the alterations of the scapulohumeral region that occur with these movements. In asymptomatic individuals, there are no statistically significant differences in scapular translation between the dominant and non-dominant arms. Patients in their postoperative recovery after shoulder surgery have significantly increased superior and medial translation of the scapula compared to 1) their asymptomatic shoulder and 2) an asymptomatic control group. A side-to-side difference of two centimeters may signify an abnormal or pathologic amount of vertical scapular translation with scaption.

**REFERENCES**


ABSTRACT

Purpose/Background: The RAZOR curl has been introduced as a hamstring exercise. However, modifications to the exercise have been developed which are proposed to utilize some of the muscles of the lumbo-pelvic-hip complex. Thus, it was the purpose of this study to quantitatively examine the modified RAZOR curl using surface electromyography (sEMG), as an exercise that may recruit the trunk muscles of the lumbo-pelvic-hip complex.

Methods: Twenty-eight active male and female graduate students (24.2±1.3 years; 174.8±9.9 cm; 74.9±14.9 kg), consented to participate. Dependent variables were muscle activation of trunk musculature (dominant side gluteus medius, gluteus maximus, multifidus, longissimus, lower rectus abdominis, upper rectus abdominis, external obliques) reported as percent of maximum voluntary isometric contraction (%MVIC) during the exercise while the independent variable was the muscle selected.

Results: The multifidus and longissimus demonstrated moderately strong activation (35-50%MVIC) while the upper rectus abdominis demonstrated strong activation (20-35%MVIC) and the gluteus medius, gluteus maximus, lower rectus abdominis, and external obliques had minimal activation.

Conclusions: These findings allow the practitioner to utilize an exercise that provides a functional training stimulus that activates not only the hamstrings but also some musculature of the trunk muscles of the lumbo-pelvic-hip complex at strong to moderately strong levels.

Level of Evidence: 5

Key Words: core control; core stabilization; functional exercises; sEMG
INTRODUCTION

Neuromuscular factors such as trunk and hamstring control and efficiency have been associated with both injury and injury prevention.1-5 Biomechanically, the body can be depicted as a kinetic link model or a kinetic chain. Dynamic stability of the kinetic chain that includes the lower extremity and trunk is based on the neuromuscular control of the lumbopelvic-hip complex.3,6,7 The lumbopelvic-hip complex is composed of the hip, pelvis, and trunk segments, including the musculature either originating from or attaching on the hip, pelvis, and trunk. Based on the body’s natural motor patterns of the neuromuscular system, the musculature of the trunk activates prior to the musculature of the lower extremity.2 In addition, dynamic stability of the trunk has been postulated to provide a stable base of support for functional movements of the upper and lower extremities,2 just as inefficient control of the trunk has been associated with hamstring injuries8 and knee pathologies spanning from patellar tendonitis to anterior cruciate ligament injuries.5

When performing sports specific movements, the musculature of the trunk must function dynamically in multiple planes. Trunk muscle control and or stability demands escalate as movements become multiplanar and increase in intensity.9 As movements become more dynamic or sport specific, the ability to make the postural corrections becomes more difficult because of the multiple planes involved, speed and complexity of the movement, and the required decrease in reaction time. There have been many proposed exercises that have targeted musculature of the lumbopelvic-hip complex due to the need for torso control and stability in dynamic movements.10-16

Recently, Oliver and Dougherty17 described a functional approach to hamstring training with the RAZOR curl, an exercise resembling the Russian hamstring curl.18 They introduced this exercise to the strength and conditioning arena in an attempt to train the hamstrings in a more sport specific position of hip flexion allowing for a more optimal and forceful contraction of the hamstrings at the knee.17 The premise of the development of the RAZOR curl was to position the hamstrings in a lengthened position, the hip must be flexed prior to the knee flexion contraction. Thus, when training athletes to maximize hamstring strength and endurance of the knee flexion function, it is important to have the hip flexed in order to elongate the proximal hamstring. Essentially, this exercise combines the hamstring benefits of the traditional Russian hamstring curl, by using a position that provides a shorter body lever. It also may bring the benefits of the traditional roman chair back extension exercise, using a bent knee position, which provides a shorter body lever to the low back. The shorter body lever position serves mainly to reduce low back load stresses, but may also provide a way to train the hamstrings in sport-specific position that incorporates both body position and closed kinetic chain motion. The RAZOR curl has been shown to exhibit adequate hamstring and gluteal activation as compared to the traditional prone hamstring curl19 and has subsequently been described as a functional exercise for hamstring training.17 However, there have been some questions about the RAZOR curl and the equipment needed for its performance. As introduced, the RAZOR curl was performed on a back extension machine. With the potential cost and lack of availability of the equipment, many have found ways to make modifications to the exercise by performing it on a flat sit-up bench. The modification allows the feet to be anchored on a sit-up bench while kneeling, knees flexed to 110 degrees and hip extended [Figure 1]. The individual then moves into the position of 90 degrees of knee and 90 degrees hip flexion [Figure 2]. Once in 90 degrees of knee and hip flexion, the individual returns to the starting position.

Figure 1. Knees flexed 110 degrees and hip extended.
The introduction of the RAZOR curl and even the modified RAZOR curl has proved to be clinically applicable, since it is anecdotally easier to perform than the traditional Russian hamstring curl. More importantly, there is a great need to address torso and hamstring training among athletes, in particular, female athletes in an effort to prevent or mitigate knee injury risk. Because several authors describe the need for neuromuscular control of the torso and hamstring for lower extremity injury prevention, the investigators wanted to examine the modified RAZOR curl in order to determine the trunk muscle activation associated with this exercise. Although the RAZOR curl activates the hamstring and gluteal muscle groups, the modified version may also influence other muscles that are part of the lumbopelvic-hip complex component. Oliver and Daugherty did not examine trunk muscle activation during the performance of the original investigation of the RAZOR hamstring exercise. As a means of hamstring training, the RAZOR curl is often implemented not only in knee rehabilitation protocols but also in injury prevention exercise regimens such as neuromuscular training for landing strategies. Dougherty and Oliver proposed that the RAZOR curl may be useful for injury prevention as compared to traditional hamstring strengthening due to the potential incorporation of some of the musculature of the lumbopelvic-hip complex, which therefore may allow it to be useful for injury prevention as compared to traditional hamstring strengthening. Therefore, it was the purpose of this study to quantitatively examine the modified RAZOR curl using surface electromyography (sEMG), as an exercise that may recruit the trunk muscles of the lumbopelvic-hip complex. The authors hypothesized that when performing the modified RAZOR curl, musculature of the lumbopelvic-hip complex would exhibit moderate activation similar to previously examined core exercises.

**METHODS**

Muscle activations were recorded through normalized surface electromyographic [sEMG] data as an average percent of the participant’s maximum voluntary isometric contraction [MVIC] while performing the modified RAZOR curl. The lumbopelvic-hip complex muscles targeted have been previously examined by sEMG and were dominant side gluteus maximus, gluteus medius, multifidus, longissimus, upper rectus abdominis, lower rectus abdominis, and external obliques.

Twenty-eight active male and female graduate students [24.2±1.3 years; 174.8±9.9 cm; 74.9±14.9 kg] consented to participate [Table 1]. Active, for the purpose of this research, was defined as participating in 30 minutes or more of strength and conditioning exercise three to five days a week without history of back or lower extremity injury in the past six months. In addition all participants were familiar with the modified RAZOR curl and implemented it into their weekly training. The modified RAZOR curl was

<table>
<thead>
<tr>
<th>Table 1. Participant demographics.</th>
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</thead>
<tbody>
<tr>
<td>Muscle</td>
</tr>
<tr>
<td>Gluteus Medius</td>
</tr>
<tr>
<td>Gluteus Maximus</td>
</tr>
<tr>
<td>Multifidus</td>
</tr>
<tr>
<td>Longissimus</td>
</tr>
<tr>
<td>Lower Abdomen</td>
</tr>
<tr>
<td>Upper Abdomen</td>
</tr>
<tr>
<td>External Obliques</td>
</tr>
</tbody>
</table>
defined as the previously described exercises utilizing a sit-up bench [Figure 1], progressing to 90 degrees of knee and 90 degrees of hip flexion [Figure 2], and then returning to the starting position. The University of Arkansas Institutional Review Board approved all testing protocols implemented in the current study and prior to any participation the procedure, risks, and benefits of the study were explained to all participants. Informed consent was obtained from each of the participants, and the rights of the participants were protected according to the guidelines of the University’s Institutional Review Board.

Participants reported to the athletic training education laboratory classroom prior to engaging in any form of physical activity that day. Locations of dominant side gluteus medius, gluteus maximus, multifidus, longissimus, upper rectus abdominis, lower rectus abdominis, and external obliques were identified by a certified athletic trainer through palpation assessment as defined by Kendall et al. Dominant side was chosen by the hand that the participant chose to hold a pencil. The skin surfaces overlying the muscle bellies prepped according to previously established protocols. After the area was clean, adhesive 3M Red-Dot [3M, St. Paul, MN] bipolar surface electrodes were attached on the muscle bellies and positioned parallel to the muscle fibers using the techniques described by Basmajian and Deluca with an inter-electrode distance of 25 millimeters.

Surface EMG data were recorded via a Noraxon Myopac 1400L 8-channel amplifier [Noraxon USA, Inc., Scottsdale, AZ]. All sEMG signals were full wave rectified and root mean squared at 100ms. Throughout all data collection, data were sampled at a rate of 1000Hz and filtered with standard band-pass filtering. Following electrode placement, two manual muscle tests [MMTs] of five seconds each were performed, by a certified athletic trainer for each muscle utilizing the techniques of Kendall. The MMTs were used to identify the MVIC for each muscle. The multifidus was tested with the participant prone, arms crossed over chest and attempting to perform back extension and rotation to the opposite side while the investigator resisted the motion. Obliques were tested with the participant supine, arms crossed over chest and the subject positioned in 45° of trunk flexion. The participant the attempted trunk flexion and rotation to the opposite side while the investigator stabilized the legs and resisted trunk flexion and rotation. The upper rectus abdominis and lower rectus abdominis MMTs were both performed with participant in a supine position, arms crossed over chest, legs in 75° of hip flexion, and pelvis in neutral position. The lower rectus was tested by the investigator pushing the participant into hip extension, while the upper rectus was tested as the patient tried to perform trunk flexion with the investigator providing resistance. The MVIC for each muscle served as the baseline reading to which the participant's sEMG activity would be compared.

Following the MMTs, the investigators instructed the participants on the proper technique for the modified RAZOR curl exercise. Participants viewed repeated demonstrations and had unlimited time to practice, with no participant performing more than 5 repetitions. The average time for the participants to get correct performance was three repetitions, since all participants were familiar with performing the RAZOR curl. During their practice trials they were given verbal feedback on proper technique. Once the participant felt comfortable with the technique, they performed three trials of the modified RAZOR curl, as described previously. Participants performed three consecutive trials with no rest period between trials. During each trial, participants were given verbal cues and feedback. Participants were informed when they reached 90 degrees of knee and hip flexion as observed by the investigators. If the participant did not achieve full range of motion, the trial was repeated. The trials in which the participant achieved full range of motion were recorded. All data were analyzed and normalized as the mean percent of each participant's MVIC over three trials.

**Data Analysis**

Descriptive statistics were used to describe muscle activation of the dominant side gluteus maximus, gluteus medius, multifidus, longissimus, upper rectus abdominis, lower rectus abdominis, and external obliques while preforming the modified RAZOR curl in terms of means and standard deviations, using GraphPad Prism 5.0 [GraphPad Software, Inc., San Diego, CA] and to determine each muscle's mean percent of MVIC. In addition, percent MVICs were categorized as minimal activation for 0-20% MVIC, moderate activation for 20-35% MVIC, moderately strong activation at 35-50% MVIC, and greater than...
50% MVIC was considered significantly high activation.26 Subsequent analyses were conducted using a two-way analysis of variance [ANOVA] using Bonferroni post hoc analyses. The level of significance was set a priori at p < 0.05.

RESULTS
The modified RAZOR curl hamstring exercise resulted minimal activation of the gluteus medius, gluteus maximus, lower rectus abdominis, and external obliques, while the upper abdominis displayed moderate activity, and the multifidus and longissimus revealed moderately strong activity. Percent of MVICs expressed as means and standard deviations are presented in Table 2.

DISCUSSION
Previously, research has described the RAZOR curl as being a functional hamstring exercise.17 As one performs the RAZOR curl there is an element of lumbopelvic-hip complex muscle activation. This study examined muscle activation of selected muscles within the lumbopelvic-hip complex during the modified RAZOR curl. The results revealed that of all the muscles examined, the multifidus and longissimus had the greatest activation, which can be described as moderately strong when expressed as %MVIC. In an attempt to compare the current study's findings to other popular exercises that have been suggested to address similar musculature of the lumbopelvic-hip complex, %MVICs reported from the RAZOR curl were compared to %MVICs previously reported from another study [Table 3].12 When focusing on muscle activation of the lumbopelvic-hip complex, the longissimus and multifidus were isolated from each study. Figure 3 represents the %MVIC reported for both muscles during the modified RAZOR curl, side-bridge, unilateral bridge, prone bridge, and lunge as derived from the present study and the previous one. The modified RAZOR curl produced similar muscle activations in the longissimus (38%MVIC) as the side-bridge (40%MVIC) and unilateral bridge (40%MVIC) exercises and activations of the multifidus during the modified RAZOR curl (35.9%MVIC) were similar to those produced during the side-bridge (42%MVIC), unilateral bridge (44%MVIC), and lunge exercises (25%MVIC).

The current study implemented a modified RAZOR curl set up while the participants performed the original RAZOR hamstring exercise. The muscle activation of the gluteus maximus and medius were the only muscles analyzed in this study that were previously examined in the original RAZOR curl study. The activations of both the gluteus medius and gluteus maximus exhibited lower percent of MVIC as compared to the values previously reported (100 and 66%MVIC respectively).19 It was postulated by the investigators that the change in positioning of the torso with the modified RAZOR curl allowed for the decreased gluteal activation.

The importance of these findings allows the practitioner to utilize the modified RAZOR curl not only as a hamstring exercise but also as an adjunct to lumbopelvic training. The main difference in the modified RAZOR curl is that from the knee and hip position of 90 degrees of flexion, the individual then extends their hip and knee in the ending position, versus the original RAZOR curl the individual stays in a position of 90 degrees of knee and hip flexion. In this position, the lumbar extensors are able to provide support due to the aid of the posterior leg muscles. However, with the hip and knee remaining flexed, the lumbar extensors may be challenged in their attempt to promote

| Table 2. Electromyographic data normalized and expressed as mean percent of MVIC while performing the modified RAZOR curl. |
|-----------------|---------|------|
| Muscle          | %MVIC Mean | SD  |
| Gluteus Medius  | 13.8    | 7.6  |
| Gluteus Maximus | 11.8    | 7.0  |
| Multifidus      | 35.9    | 21.7 |
| Longissimus     | 38.0    | 40.8 |
| Lower Abdomen   | 6.1     | 6.8  |
| Upper Abdomen   | 24.4    | 27.4 |
| External Obliques| 17.7   | 17.4 |
postural awareness and maintenance of a neutral lumbar curve. The neutral lumbar curve, along with the demands of torso control, during the modified RAZOR curl may address low back muscle endurance and motor control of the lumbar extensors, although neither of these constructs were examined in the current study. Both are critical aspects of trunk extensor training that may serve to not only reduce low back injury risk but also decrease risk of knee injury and should be examined in future research.

Table 3. Electromyographic data normalized and expressed as mean percent of MVIC of different core exercises.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>%MVIC Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIDE BRIDGE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gluteus Medius</td>
<td>74</td>
<td>30</td>
</tr>
<tr>
<td>Gluteus Maximus</td>
<td>21</td>
<td>16</td>
</tr>
<tr>
<td>Multifidus</td>
<td>42</td>
<td>24</td>
</tr>
<tr>
<td>Longissimus</td>
<td>40</td>
<td>17</td>
</tr>
<tr>
<td>Abdomen</td>
<td>34</td>
<td>13</td>
</tr>
<tr>
<td>External Obliques</td>
<td>69</td>
<td>26</td>
</tr>
<tr>
<td>UNILATERAL BRIDGE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gluteus Medius</td>
<td>46</td>
<td>24</td>
</tr>
<tr>
<td>Gluteus Maximus</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>Multifidus</td>
<td>44</td>
<td>18</td>
</tr>
<tr>
<td>Longissimus</td>
<td>40</td>
<td>16</td>
</tr>
<tr>
<td>Abdomen</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td>External Obliques</td>
<td>23</td>
<td>16</td>
</tr>
<tr>
<td>PRONE BRIDGE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gluteus Medius</td>
<td>27</td>
<td>11</td>
</tr>
<tr>
<td>Gluteus Maximus</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>Multifidus</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Longissimus</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Abdomen</td>
<td>43</td>
<td>21</td>
</tr>
<tr>
<td>External Obliques</td>
<td>47</td>
<td>21</td>
</tr>
<tr>
<td>LUNGE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gluteus Medius</td>
<td>29</td>
<td>12</td>
</tr>
<tr>
<td>Gluteus Maximus</td>
<td>36</td>
<td>17</td>
</tr>
<tr>
<td>Multifidus</td>
<td>25</td>
<td>11</td>
</tr>
<tr>
<td>Longissimus</td>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td>Abdomen</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>External Obliques</td>
<td>17</td>
<td>11</td>
</tr>
</tbody>
</table>

All data reported by Ekstrom et al. 2007

![Figure 3](image-url)  
**Figure 3.** Percent of MVIC significantly different from the %MVIC produced using the RAZOR curl exercise within the corresponding muscle (p < 0.05).
study that examined similar muscle activations during other common core exercises. The current study revealed a high level of muscle activity in the longissimus and multifidus. This is significant because the multifidi are deep spinal muscles that stabilize against spinal rotation and forward flexion as well as contribute to dynamic stability of the sacroiliac joint. The longissimus muscle group produces a high extensor moment with minimal compressive penalty to the spine due to architectural alignment being directly under the lumbodorsal fascia of the spine. This produces an optimal line of pull along the spine that gives it the greatest possible moment arm. It is important to recognize that the optimal stabilization of the torso occurs when the relevant core muscles, such as the transverse abdominis and multifidus, fire synergistically to create ideal dynamic stability via coordinated motor control and muscle contraction synchrony.

The results of the current study must be interpreted with caution when determining if strengthening of the trunk musculature could occur during performance of this exercise. Although the multifidus and longissimus demonstrated moderately strong activity and the greatest of the muscles examined, the level of activity produced by the modified RAZOR exercise may not be sufficient to provide a muscular strengthening stimulus. Previous authors have reported that muscular strengthening requires 50-60% MVIC.

Essentially, it is the coordination and neuromuscular control of both the longissimus and multifidus along with the rectus abdominis and obliques that may enhance lumbopelvic-hip stability. The rectus abdominis and obliques are prime movers for trunk flexion and rotation. The oblique muscle group is activated in direction specific patterns in effort to support the pelvis prior to limb movement. Although the multifidus and longissimus have different attachment sites and functions, both have a muscle fiber arrangement that serves to protect the back against anterior shear forces commonly seen in a forward flexed posture. Another important component of these two muscles is that they also serve to function eccentrically in order to control descent of the trunk during forward bending and isometrically control the position of the lower thorax in relation to the pelvis during functional movements.

The fact that all muscles of the trunk examined [upper and lower abdominis, external obliques, multifidus, longissimus, gluteus medius, and gluteus maximus] were active, ranging from minimal to moderately strong, does reveal that the trunk prime movers and stabilizers are targeted when performing the modified RAZOR curl. The current findings reinforce the importance of not only posterior leg and torso training, but also help offer an exercise that may be functional, yet is still practical. Therefore, the modified RAZOR curl is a practical exercise that can be easily adapted and more importantly, provide moderate to moderately strong recruitment to selected musculature of the lumbopelvic-hip complex. When combined with earlier research, it appears that this exercise can recruit both lumbo-pelvic muscles and the hamstrings.

**LIMITATIONS**

The use of sEMG on the multifidus muscle group could be regarded as a limitation. The multifidus muscle group is complex, in that there are superficial and deep fibers. However, it is difficult to differentiate between them both anatomically and biomechanically. It has been proposed, based on the anatomy of the superficial multifidus [those examined in the current study], that this muscle provides both efficient control of lumbar extension as well as spinal orientation control. A second limitation was the use of sEMG. Although electrode placement was in accordance to Kasman et al, sEMG does have a limitation of cross-talk between electrodes. The nature of sEMG often allows for cross-talk among muscles that are close in proximity. In addition, it has been noted that when trying to recorded sEMG of the multifidus, the longissimus muscle activity is often recorded instead. When keeping with the sEMG protocol, it is recommended that if it is the multifidus that are of interest, then further investigation of the longissimus should also be included in attempt to differentiate between the two muscle activations. In addition, the deep fibers of the multifidus should be addressed by indwelling fine wire electrodes versus surface electrodes.

**CONCLUSION**

Neuromuscular function of the lumbopelvic-hip complex can be considered an important element in core and resultant lower body movement control and efficiency. There is great need for intervention among athletes participating in power sports due to the
increased incidence of low back and knee injuries. Neuromuscular training can significantly cut down on the number of low back and knee injuries among athletes, especially with female athletes. The present study introduced and examined the muscular recruitment during the modified RAZOR curl using a sit-up bench. The findings of the current study may provide practitioners a new time-efficient exercise for recruiting muscles important to core and hip stability.

Furthermore, the beneficial effects of the RAZOR curl for activating musculature of the lumbopelvic-hip complex were described. Therefore, the modified RAZOR curl is a practical and functional exercise that can be easily adopted with various equipment and provide an opportunity to train the hamstrings in a functional manner while providing a stability challenge to important torso musculature.

REFERENCES
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34. Hodges PW, Richardson CA. Feedforward contraction of transversus abdominis is not influenced by the direction of arm movement. Exp Brain Res. 1997;114:362-370.


ABSTRACT

**Purpose:** The purpose of this systematic review was to examine the link between training characteristics (volume, duration, frequency, and intensity) and running related injuries.

**Methods:** A systematic search was performed in PubMed, Web of Science, Embase, and SportDiscus. Studies were included if they examined novice, recreational, or elite runners between the ages of 18 and 65. Exposure variables were training characteristics defined as volume, distance or mileage, time or duration, frequency, intensity, speed or pace, or similar terms. The outcome of interest was Running Related Injuries (RRI) in general or specific RRI in the lower extremity or lower back. Methodological quality was evaluated using quality assessment tools of 11 to 16 items.

**Results:** After examining 4561 titles and abstracts, 63 articles were identified as potentially relevant. Finally, nine retrospective cohort studies, 13 prospective cohort studies, six case-control studies, and three randomized controlled trials were included. The mean quality score was 44.1%. Conflicting results were reported on the relationships between volume, duration, intensity, and frequency and RRI.

**Conclusion:** It was not possible to identify which training errors were related to running related injuries. Still, well supported data on which training errors relate to or cause running related injuries is highly important for determining proper prevention strategies. If methodological limitations in measuring training variables can be resolved, more work can be conducted to define training and the interactions between different training variables, create several hypotheses, test the hypotheses in a large scale prospective study, and explore cause and effect relationships in randomized controlled trials.

**Level of evidence:** 2a

**Key words:** Duration, frequency, injuries, intensity, running, training, volume

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INTRODUCTION

Weight loss and smoking cessation have been associated with running,1 and it has been stated that running has positive effects on health and fitness.2 However, Running Related Injuries (RRI) of the lower extremities are commonly a negative side effect. Depending on injury definition and length of follow up period, the injury incidence among runners varies between 11–85%,1,3,14 or 2.5 to 38 injuries per 1000 hours of running.9,16-18 Several risk factors contributing to injuries have been reported18-21 and general consensus exists with regard to training characteristics and previous running injuries being associated with the development of RRI. Training characteristics are of particular importance, since the training regimen is under the control of the runners (and coaches) and can be modified in contrast to previous injuries which cannot be modified.22,23 Furthermore, anecdotal evidence suggests that training errors (i.e. excessive distance, sudden change of training routines, etc.) are the cause of 60–70% of all running injuries.16,24,25 In a review of the etiology and prevention of and intervention for overuse injuries in runners, Hreljac20 concluded that the causes of all overuse running injuries could be classified as training errors, and thus, all overuse running injuries should be preventable. In order to summarize and present the information that examines the evidence about training errors and RRI, a systematic review may be a starting point to identify which training errors have been reported to be associated with injury development. To date, the authors have found no published systematic review that aims to present an overview of the literature, investigating the relation between volume, duration, intensity, and frequency of running, herein defined as training characteristics, and the development of RRI. Therefore, the purpose of this systematic review was to investigate the association between training characteristics and running related injuries.

METHOD

Search strategy and inclusion criteria

The Cochrane database was searched, revealing no systematic reviews about training characteristics and RRI. A search of the Pubmed, Web of Science, Embase, and Sportdiscus databases was conducted October 11th 2011 to identify studies that met the inclusion criteria using the search strategy presented in Appendix 1. The search was limited to studies of humans, published in English, and included only original articles.

Prospective cohort studies, cross-sectional studies, case-control studies, and randomized controlled trials were included in the current systematic review if a relationship between training characteristics and RRI was investigated. Studies with novice, recreational, and elite runners between the ages of 18 to 65 were included. Articles were excluded if participants were sprinters or middle distance runners, or were predominantly exposed to types of sporting activity other than running such as triathlons, and military training programs. Articles on cadavers, computer modeling/simulation studies were excluded.

The exposure variables of interest were training characteristics including volume, distance, mileage, time, duration, frequency, intensity, speed, and pace. Different methods for analyzing or reporting these characteristics were accepted. For instance, volume could be measured as kilometers or miles per day, per week, per month or as the gradual increase in mileage per week over a given period of time. The outcome of interest was RRI in general or specific RRI of the lower extremity or spine. Muscle cramps, corns, blisters, and calluses were not included as RRI.

Data collection and analysis

Each study identified as a result of the electronic search was initially evaluated independently by two authors (RON and IB) by screening the title and abstract. Articles without an abstract were excluded. All articles of interest were retrieved and evaluated for eligibility. Articles were excluded if no information was provided on injuries during follow up, in case of overview articles, or articles about degenerative diseases only.

Methodological quality assessment

The methodological quality of the cross sectional studies, case-control studies, and prospective cohort studies was assessed by means of a methodological quality assessment list developed and used by van der Worp et al.26 which was based on a list developed by van der Windt et al.27 The list was adapted slightly to make it specific for training and RRI. The assessment contains
items on information and validity and/or precision in five categories: study objective, study population, outcome measurements, assessment of the outcome, and analysis and data presentation. Separate quality assessment lists were constructed for cross-sectional studies, case-control studies, and prospective cohort studies. The items of the quality assessment list are presented in Table 1. Each item was evaluated as either positive (+) or negative (-) by two reviewers independently. In cases where it was unclear whether a study did or did not meet an item, or if no clear information regarding the item was stated, the item was scored as negative (-).

Results of the quality assessment made by the two reviewers were compared, and any disagreement concerning an item was resolved in a consensus meeting. The total quality of each study was calculated by counting the number of items being positive (+) from item 3 to 16 divided by the total number of items for the study type (11 for case-control studies, 9 for prospective cohort studies, and 8 for cross sectional studies).

The methodological quality of the randomized controlled trials included was rated using the PEDro rating scale which is based on the Delphi list developed by Verhagen and colleagues. The total methodological quality score was found by evaluating the internal validity and statistical reporting using an 11 criteria list. The total quality of each randomized controlled trial was calculated by counting the number of items being positive (+) from item 2 to 11 divided by 10. Previously, the PEDro scale has demonstrated an inter-rater agreement of $k = 0.73–0.82$.

Results

After examining 4561 titles and abstracts, 62 articles were identified as potentially relevant. After reference checking, one additional study was identified. The full texts of all 63 articles were retrieved and were subsequently evaluated by both RON and IB. Review of the complete texts excluded 32 articles. Of the excluded articles, four were overview articles, four included persons less than 18 years of age, three included persons with degenerative diseases only, eight articles did not describe the relationship between training characteristics and RRI, three had no control group, eight articles did not describe the relationship between training characteristics and RRI, and one was a design article. Finally, 30 articles were included in the review.

Risk of bias in included studies

The quality of included studies is presented in Table 2. The overall methodological quality of the included prospective studies, case-control studies, and cross sectional studies was 44.1% ranging from 9 to 89%. The most problematic areas were 1) the main purpose of many of the studies was different than the relation between training and RRI, 2) description of the demographic characteristics (gender, age, body mass index) of the participants was lacking, and 3) lack of adjustment for the effect of multiple training variables. The overall quality of the three randomized controlled trials was 43%.

Description of studies and injury definition

The year of publication for the included studies ranged from 1977 to 2008. The studies represented populations in USA, Canada, New Zealand, The Netherlands, Denmark, Switzerland, Germany, and Sweden. The total sample size of included participants was 24,066, ranging from 28 to 4,335 subjects in each study. Of the 30 included studies, nine were retrospective cohort studies, 12 were prospective cohort studies, six were case-control studies, and three randomized controlled trials. The study characteristics of the selected studies were described to obtain insight into the homogeneity of the study populations (Table 3). The types of participants (novice, recreational, and elite), and the injury definition used varied considerably between the studies. For instance, Lysholm et al used “all injuries that markedly hampered training or competition for at least 1 week were noted” while Valliant used “injury was defined as physiological damage or bodily pain which interfered with one’s ability to run”. The mean age of all participants in the 30 studies varied from 19.5 years to 44 years with an average of 35.4 years. Mean body mass index was 22, ranging from 20.97 to 25.86. Four studies included only males while two included only females. For the remaining studies, an average of 67.6% of the participants included were males. Table 3 presents summary data from each study regarding the type of runner, demographic characteristics, and injury definition as quoted verbatim from the article.

Description of training characteristics

In 22 studies, the training characteristics were assessed retrospectively by a questionnaire. The recall period varied from two weeks to 10 years. In eight studies,
Table 1. Summary of quality scoring criteria for cross-sectional studies, case control studies, and prospective cohort studies.

<table>
<thead>
<tr>
<th>Category</th>
<th>Study type</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Study objective</strong></td>
<td></td>
</tr>
<tr>
<td>1 Positive, if the study had a clearly defined objective and the main purpose was to investigate the relation between training characteristics and RRI</td>
<td>CS / CC / PC</td>
</tr>
<tr>
<td><strong>Study population</strong></td>
<td></td>
</tr>
<tr>
<td>2 Positive, if the main features of the study population are described (sampling frame and demographic characteristics)</td>
<td>CS / CC / PC</td>
</tr>
<tr>
<td>3 Positive, if cases and controls are drawn from the same population and a clear definition of cases and controls is given and if subjects with RRI in the past 3 months are excluded.</td>
<td>CC</td>
</tr>
<tr>
<td>4 Positive, if the participation rate is at least 80% or if the participation rate is 60-80% and the non-response is not selective (data shown).</td>
<td>CS / CC / PC</td>
</tr>
<tr>
<td>5 Positive, if the participation rate at main moment of follow-up is at least 80% or if the non-response is not selective (data shown).</td>
<td>PC</td>
</tr>
<tr>
<td><strong>Outcome measurements</strong></td>
<td></td>
</tr>
<tr>
<td>6 Positive, if data on history of RRI is collected and included in the statistical analysis.</td>
<td>CS / CC / PC</td>
</tr>
<tr>
<td>7 Positive, if the outcome is measured in an identical manner among cases and controls.</td>
<td>CC</td>
</tr>
<tr>
<td>8 Positive, if the outcome assessment is blinded with respect to RRI status</td>
<td>CS / CC</td>
</tr>
<tr>
<td>9 Positive, if the outcome is assessed at a time before the occurrence of RRI.</td>
<td>CC</td>
</tr>
<tr>
<td><strong>Assessment of the outcome</strong></td>
<td></td>
</tr>
<tr>
<td>10 Positive, if the time period on which the assessment of RRI was based was at least 1 year.</td>
<td>PC</td>
</tr>
<tr>
<td>11 Method for assessing injury status: physical examination blinded to exposure status (+); self-reported: specific questions relating to symptoms/disease/use of manikin (+), single question (-).</td>
<td>CS / CC / PC</td>
</tr>
<tr>
<td>12 Positive, if incident cases were included (prospective enrollment).</td>
<td>CC</td>
</tr>
<tr>
<td><strong>Analysis and data presentation</strong></td>
<td></td>
</tr>
<tr>
<td>13 Positive, if the measures of association estimated were presented (OR / RR), including CI and numbers in the analysis.</td>
<td>CS / CC / PC</td>
</tr>
<tr>
<td>14 Positive, if the analysis is controlled for confounding or effect modification: individual factors (BMI, previous injuries etc.).</td>
<td>CS / CC / PC</td>
</tr>
<tr>
<td>15 Positive, if the analysis is controlled for confounding or effect modification: Training related factors.</td>
<td>CS / CC / PC</td>
</tr>
<tr>
<td>16 Positive, if the number of cases in the final multivariate model was at least 10 times the number of independent variables in the analysis.</td>
<td>CS / CC / PC</td>
</tr>
</tbody>
</table>

CS = cross-sectional studies. CC = case-control studies. PC = prospective cohort studies. RRI = Running Related Injuries.
daily running diaries\(^9,16,17,30,62-64\) or an internet based log\(^15\) were used. In five studies, training interventions were used.\(^5,9,15,17,30\) Odds Ratio (OR), Hazard Ratio (HR), and Relative Risk (RR) were the most common measures of association. The unit of measurement in this review is miles. However, some articles used kilometers. In these cases, kilometers were converted into miles using 0.62137 as conversion factor. Different definitions were used in the reviewed studies for training volume, duration, intensity, and frequency.

### Volume

In 28 articles out of 30 articles, the link between training volume and RRI was investigated. The most commonly used approach to define exposure was to measure the average weekly miles\(^4,13,14,16,22,61-63,65-69\) or kilometers\(^10,11,17,70\) of running over a period of time. In other studies, weekly distance per week frequency\(^7\) or total running distance\(^64,71\) were used as the measure of exposure.

### Duration

In three articles, average hours\(^9,17,69\) or minutes\(^15\) spent running per week were used as the exposure variable. In another study, the weekly progressive increase in duration during a graded training program was used,\(^15\) while two other studies used minutes per day\(^3,30\) as their measure of exposure.

### Intensity

In 16 articles, training intensity was described.\(^1,4,9,11,13,14,17,22,63-70\) In a majority of these, average pace of...
### Table 3. Descriptions of included studies characteristics. Injury definitions are quoted verbatim unless stated otherwise.

<table>
<thead>
<tr>
<th>Author, year</th>
<th>Running type</th>
<th>Included / Analyzed</th>
<th>Description of population</th>
<th>Injury definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bovens 1989</td>
<td>Healthy untrained volunteers with the goal of running a marathon within 1½ years</td>
<td>115 / 73 = 63.5 %</td>
<td>M / F: 58 / 15 Age: 35 ± 8 (M), 33 ± 6.4 (F) BMI: 22.67 (M) 20.97 (F)</td>
<td>“Any physical complaint developed in relation with running activities and causing restriction in running distance, speed, duration, or frequency, was considered to be an injury.”</td>
</tr>
<tr>
<td>Buist 2008</td>
<td>Healthy novice runners</td>
<td>603 / 486 = 80.6 %</td>
<td>M / F: 180 / 306 Age: 39.8 ± 10.1 BMI: 24.9 ± 3.5</td>
<td>“An RRI was defined as any musculoskeletal complaint of the lower extremity or back causing a restriction of running for at least one week.”</td>
</tr>
<tr>
<td>Colbert 2000</td>
<td>Cases</td>
<td>5327 / 3923 = 73.6 %</td>
<td>M / F: 698/169 Age: N / A BMI: N / A</td>
<td>“Injury related to physical activity during the 12 months immediately preceding the survey that necessitated a physician visit.”</td>
</tr>
<tr>
<td></td>
<td>Controls</td>
<td></td>
<td>M / F: 2358 / 698 Age: N/A BMI: N / A</td>
<td>Same as Messier 1995 + “The diagnosis of anterior knee pain was based on clinical examination...”</td>
</tr>
<tr>
<td>Duffey 2000</td>
<td>Same as Messier 1995</td>
<td></td>
<td>M / F: 53 / 17 Age 35 ± 1 BMI: 22.9 ± 0.3</td>
<td>Same as Messier 1995 + “The diagnosis of anterior knee pain was based on clinical examination...”</td>
</tr>
<tr>
<td></td>
<td>Cases /AKP</td>
<td></td>
<td>M / F: 68 / 31 Age: 36 ± 1 BMI: 23.3 ± 0.3</td>
<td></td>
</tr>
<tr>
<td>Fields 1990</td>
<td>Participants had to train an average of 3 days and run at least 10 miles per week</td>
<td>51 / 40 = 78.4 %</td>
<td>M / F: 31 / 9 Age: N / A BMI: N / A</td>
<td>“An injury was defined as any musculoskeletal problem occurring during running that interrupted training for 1 or more days.”</td>
</tr>
<tr>
<td>Hootman 2002</td>
<td>Persons who had been running at least 1 year from 1981 to 1985</td>
<td>11972 / 3090 = 25.8 %</td>
<td>M / F: 2.481 / 609 Age: N / A BMI: N / A</td>
<td>“First reported lower extremity injury requiring consultation with an physician that occurred after the start of an RWJ program and during the 5 year recall period” or “lower extremity injury requiring consultation with an physician during the 12-months recall period”</td>
</tr>
<tr>
<td>Jacobs 1986</td>
<td>Runners participating in ‘National Championship’ USA 1985</td>
<td>550 / 451 = 0.82 %</td>
<td>M / F: 355/96 Age: 33.9 (M) 32.4 (F) BMI: N / A</td>
<td>“A runner was considered to have been injured...if the pain caused a restriction in running distance or speed, or prevented any running at all.”</td>
</tr>
<tr>
<td>Jakobsen 1994</td>
<td>Recreational long distance runners (marathon)</td>
<td></td>
<td>M / F: 18 / 2 Age: 43.1 BMI: 22.9</td>
<td>“An injury was defined as any injury of the musculoskeletal system that was sustained during running and prevented training or competition”</td>
</tr>
<tr>
<td></td>
<td>Intervention:</td>
<td></td>
<td>M / F: 19 / 2 Age: 40.6 BMI: 22.5</td>
<td></td>
</tr>
<tr>
<td>Kelsey 2007</td>
<td>Female cross-country runners running at least 40 miles per week during peak training times.</td>
<td>150 / 127 = 84.6 %</td>
<td>Female only Age: 22 ± 2.6 BMI: 21.2 ± 1.9</td>
<td>“Participants were asked to record the occurrence of a possible stress fracture on a monthly calendar and also to report their occurrence to us immediately. The fracture had to be confirmed by x-ray, bone scan, or magnetic resonance imaging to be counted in this study.”</td>
</tr>
<tr>
<td>Knobloch 2008</td>
<td>Elite</td>
<td>291 / 291 = 100%</td>
<td>M / F: 248 / 41 Age: 42 ± 9 BMI: 23 ± 2.2</td>
<td>“Any physical complaint sustained by a runner that result from a running competition or training, irrespective of the need for medical attention or time lost from running activities”</td>
</tr>
<tr>
<td>Koplan 1982</td>
<td>Participants in 10 km. road race.</td>
<td>2500 / 1423 = 56.9 %</td>
<td>M / F: 730 / 693 Age: 33.4 (M) 29.9 (F) BMI: N / A</td>
<td>“An injury was defined as a musculoskeletal ailment attributed to running that caused the runner to reduce the weekly mileage, take medicine, or visit a health professional.”</td>
</tr>
</tbody>
</table>
Table 3. (Continued) Descriptions of included studies characteristics. Injury definitions are quoted verbatim unless stated otherwise.

<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>Injury Definition</th>
<th>Gender</th>
<th>Age</th>
<th>Body Mass Index</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Koplan 1995</td>
<td>Recreational</td>
<td>742 / 535 = 72.1%</td>
<td>M / F: 321 / 214</td>
<td>Age: N / A</td>
<td>BMI: 24.6 (M) 21.5 (F)</td>
<td>&quot;A musculoskeletal ailment that caused respondents to reduce or cease exercise or interfered with their work or school activities&quot;</td>
</tr>
<tr>
<td>Lysholm 1987</td>
<td>Long distance runners.</td>
<td>Male only</td>
<td>Age: 34.5 ± 7.4</td>
<td>BMI: N / A</td>
<td>&quot;All injuries that markedly hampered training or competition for at least 1 week were noted&quot;</td>
<td></td>
</tr>
<tr>
<td>Macera 1989</td>
<td>Habitual runners</td>
<td>1576 / 583 = 37%</td>
<td>M / F: 483 / 98</td>
<td>Age: 41.6 ± 9.5 (M) 36.1 ± 8.2 (F)</td>
<td>BMI: 23.0 ± 2.2 (M) 25.8 ± 2.4 (F)</td>
<td>&quot;Self reported &quot;muscle, joint or bone problem/injury&quot; of the lower extremities (foot, ankle, achillioesthesia, calf, shin, knee, thigh, or hip) that the participant attributed to running. The problem had to be severe enough to cause a reduction in weekly distance, a visit to a health professional, or the use of medication.&quot;</td>
</tr>
<tr>
<td>Marti 1988a</td>
<td>Participants in 10 mile road race.</td>
<td>Male only</td>
<td>Age: 35.0 ± 10.0</td>
<td>BMI: 22.51 ± 1.98</td>
<td>&quot;Grade I injuries involved maintenance of full training activity in spite of symptoms; grade II, a reduction of training activity, and grade III, full training interruption defined as &quot;involuntary complete interruption of running of at least two weeks duration.&quot;</td>
<td></td>
</tr>
<tr>
<td>Marti 1988b</td>
<td>Female runners participating in 10 mile road race.</td>
<td>Female only</td>
<td>Age: N / A</td>
<td>BMI: N / A</td>
<td>Same as Marti 1988a</td>
<td></td>
</tr>
<tr>
<td>McCrory 1999</td>
<td>Same as Messier 1995</td>
<td>Controls</td>
<td>M / F: N / A</td>
<td>Age: 34.5 ± 1.2</td>
<td>BMI: 23.45</td>
<td>&quot;Achilles tendinitis was defined as inflammation and irritation of the achilles tendon 2-6 cm above its insertion into the calcaneus.&quot;</td>
</tr>
<tr>
<td>McKean 2006</td>
<td>Participants in a running relay race</td>
<td>6823 / 2886 = 42.3%</td>
<td>M / F: N / A</td>
<td>Age: N / A</td>
<td>BMI: N / A</td>
<td>&quot;An event that affected the athlete’s ability to train or race over the previous 1 year period&quot;</td>
</tr>
<tr>
<td>Mechelen 1993</td>
<td>Runners with at least 10 km / week all year around</td>
<td>421 / 326 = 77.4%</td>
<td>Male only</td>
<td>Age: N / A</td>
<td>BMI: N / A</td>
<td>&quot;A running injury was defined as any injury that occurred as a result of running and caused one or more of the following: 1) the subject had to stop running; 2) the subject could not run on the next occasion; 3) the subject could not go to work the next day; 4) the subject needed medical attention; 5) the subject suffered from pain or stiffness during 10 subsequent days while running.&quot;</td>
</tr>
<tr>
<td>Messier 1995</td>
<td>Recreational and competitive runners who had been running a minimum of 10 miles / week for at least a year</td>
<td>Controls: M / F: 53 / 17</td>
<td>Age: 35.0 ± 1.2</td>
<td>BMI: 23.8</td>
<td>ITBFS group: M / F: 33 / 23</td>
<td>Age: 33.9 ± 1.2</td>
</tr>
<tr>
<td>Messier 1991</td>
<td>Same as Messier 1995.</td>
<td>Controls: M / F: 12 / 4</td>
<td>Age: N / A</td>
<td>BMI: N / A</td>
<td>Cases: M / F: 14 / 6</td>
<td>Age: N / A</td>
</tr>
<tr>
<td>Messier 1988</td>
<td>Same as Messier 1995</td>
<td>Controls: M / F: N / A</td>
<td>Age: N / A</td>
<td>BMI: N / A</td>
<td>Cases: M / F: N / A</td>
<td>Age: N / A</td>
</tr>
</tbody>
</table>
workout was used to express intensity during training, measured as minutes per mile (min/mile) or minutes per kilometer (min/km). Other studies used kilometers per hour, 16 km running time, or percentage of maximal attainable heart rate.

**Frequency**

The number of weekly training sessions was reported in a variety of ways as number of training sessions, 71 times, 22 days, 5,11,13,30,64 runs, or workouts per week. Most often the data were analyzed by dividing the weekly amount of days running into different categories. The comparisons vary widely across studies, however. The reference groups were defined as either 1, 1-2, 1-3, 1-4, or 1-5 days per week, and were compared to either one or several exposure groups varying between 3, 4, 5, 6, 7, 4-5, 5-7, 6-7 days per week. In one article, a regression model was used to investigate the risk of RRI as the weekly frequency increased during training prior to a marathon.

<table>
<thead>
<tr>
<th>Table 3. (Continued) Descriptions of included studies characteristics. Injury definitions are quoted verbatim unless stated otherwise.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Middelkoop 2008</strong> Marathoners 1500 / 694 = 46.3 % Male only Age: 44 ± 9.6 BMI: 23.5 ± 2.1 “Self-reported injury on muscles, joints, tendons and/or bones of the lower extremities (hip, groin, thigh, knee, lower leg, ankle, foot, and toe that the participant attributed to running. The problem had to be severe enough to cause a reduction in the distance, speed, duration or frequency of running.”</td>
</tr>
<tr>
<td><strong>Pollock 1977</strong> Sedentary prison inmates 122 / 157 = 77.7 % M / F: N / A Age: N / A BMI: N / A A training related incident that prevented a subject from jogging for at least one week</td>
</tr>
<tr>
<td><strong>Reinking 2007</strong> Collegiate cross-country athletes 124 / 67 = 54 % M / F: 44 / 44 Age: 19.5 BMI: N / A Self-reported ERI.P based on the athletes received additional explanation regarding the definition of leg pain. (Corrected by the Authors)</td>
</tr>
<tr>
<td><strong>Satterthwaite 1999</strong> Marathoners 1357 / 875 = 64.5 % M / F: N / A Age: N / A BMI: N / A Stiffness or pain in the hip, front thigh, hamstrings, knee or calf (Corrected by the Authors)</td>
</tr>
<tr>
<td><strong>Taunton 2003</strong> Novice and intermediate runners 1020 / 844 = 82.7 % M / F: 205 / 635 Age: N / A BMI: N / A “Grade 1 injury (pain only after exercise) or greater” Authors remark: The grading system is different from Marti 1988a</td>
</tr>
<tr>
<td><strong>Valliant 1981</strong> Participants in a 5-, 6- or 10-mile race 80 / 41 = 51.3 % M / F: N / A Age: N / A BMI: N / A “Injury was defined as physiological damage or bodily pain which interfered with one's ability to run.”</td>
</tr>
<tr>
<td><strong>Walter 1989</strong> Runners participating in 3.5 – 14 mile running events 2524 / 1288 = 51 % M / F: 985 / 303 Age: N / A BMI: N / A “Injuries are defined as severe enough to reduce the number of miles run, take medicine, or see a health professional”</td>
</tr>
<tr>
<td><strong>Wen 1997</strong> Runners preparing for marathon 304 / 355 = 85.6 % M / F: 133 / 171 Age: 41.1 ± 10.6 BMI: 25.76 (M) 23.7 (F) “Subject answered yes to having had injury or pain to that anatomic part, and answered yes to having had to stop training, or to have to slow pace, stop intervals, or otherwise to have had to modify training, and the onset of the injury was gradual (vs. immediate), or his or her diagnosis was one that is generally considered an overuse injury.”</td>
</tr>
<tr>
<td><strong>Wen 1998</strong> Runners preparing for marathon 355 / 255 = 71.8 % M / F: 102 / 153 Age 41.3 ± 10.8 BMI: 25.86 (M) 24.22 (F) Same as Wen 1997</td>
</tr>
</tbody>
</table>

**Relationship between training characteristics and RRI**

**Volume**

Hootman et al found an increased risk of injury among males (HR = 1.66 [1.43, 1.94]) and females (HR = 2.08 [1.45, 2.98]) running more than 20 miles per week. Lysholm et al found a significant correlation (r = 0.59) in long-distance/marathon runners between the distance covered in a given month and the number of injury days during the following month. Walter et al found no significant difference in relative risk between the reference group who ran less than 10 miles per week and the groups who ran distances between 10 and 39 miles per week. However, the relative risk of injury was significantly higher among males (2.22 [1.30-3.68]) and females (3.42 [1.42-7.85]) running ≥40 miles per week. This was supported by Macera et al who found a significantly increased odds ratio for sustaining injury among males running ≥40 miles per week over a period of 3 months (2.9 [1.1-7.5]). In the same study,
no association was found between weekly mileages and risk of injury among women.22 Although a majority of studies reported a relationship between weekly mileage and RRI, no significant association between miles per week and likelihood of injury was found in two prospective studies and one retrospective study.7,62,74

In retrospective studies, several authors compared total volume per week between injured and non-injured subjects. Koplan et al12 investigated the proportion of injuries over a 10 year period in different mileage strata. The proportion of women reporting injury was highest in those who ran 40-49 miles per week. For men, the proportion was highest among those who ran 30-39 miles per week. Those running more or less miles per week had a smaller proportion of injuries. Marti et al14 found that runners who sustained injuries during the study period ran greater weekly mileage when compared to non-injured runners (26.3 km [3.2-83.8] versus 22.0 km [2.1-78.6], p 0.01). In a one-way analysis, Valliant61 also indicated that injured runners ran significantly more miles per week than non-injured runners (47.5 ± 20.5 miles versus 29.6 ± 16.7 miles, p < 0.01). This is supported by Jacobs et al13 and Koplan et al12 who found mileage run per week to be highly associated with injury.

In two studies, the RRI per 1000 hours of running in groups running different mileages per week were investigated.9,17 The number of injuries per 1000 hours of running appeared to decrease with increasing weekly mileage (Figure 1).

Walter et al11 investigated the relationship between longest run per week and risk of injury. The relative risk of sustaining an injury when the longest run each week is >5 miles, is 2.49 [1.64-3.71] among males and 1.78 [0.99-3.13] among females compared with a reference group having their longest run below 5 miles. Van Middelkoop et al7 measured weekly distance per weekly frequency. Running an average of 6.8–9.3 miles per training session was not associated with increased or decreased risk of sustaining an injury compared to average runs above or below 6.8–9.3 miles.

Several authors have investigated the relationship between training volume and specific running injuries. Reinking et al10 investigated subjects sustaining exercise related lower leg pain and found no significant difference in injuries between individuals training more or less than 40 miles per week. Satterthwaite et al6 found an increased odds ratio for hamstring (1.07 [1.02, 1.13]) and knee (1.13 [1.04, 1.23]) injuries by a weekly increase in mileage of 6 miles. Wen et al69 found a significant difference in weekly mileage between subjects sustaining hip (18.7 miles per week) or hamstring injuries (22.4 miles per week) compared to controls (13.3 and 13.4 miles per week). Kelsey et al8 found miles run per week in the past year to be non-predictive of stress fractures. Wen et al69 found weekly mileage and hours per week protective against overall injuries, knee injuries, and foot injuries. In case-control studies, no difference in weekly mileage was found between controls and persons with patellar fasciitis,65 shin splints,65 achilles tendinitis,70 or anterior knee pain,65 while patients with patellofemoral

### Figure 1. Relationship between miles per week and Running Related Injury (RRI) reported as mean [95% confidence interval] for different comparisons. Results from the articles by Bovens and Jakobsen are calculated based on figures in the articles. RRI = Running Related Injury. Adj = adjusted. Hrs = Hours.
pain ran significantly less than healthy controls.\textsuperscript{66} For iliotibial band friction syndrome, Messier and colleagues found conflicting results in two different studies. In one study, injured participants ran significantly less than healthy controls, and in the other study no significant difference in weekly mileage between injured and healthy participants was reported.\textsuperscript{65,67}

**Duration**

Pollock et al\textsuperscript{30} found an increasing injury incidence among novice runners who ran in 15, 30, and 45 minute duration groups of 22\%, 24\%, and 54\%, respectively. Jakobsen et al\textsuperscript{17} reported 7.4 and 6.9 RRI per 1000 hours of running among marathon runners who ran 204 [95\% CI: 198-210] and 162 [95\% CI: 156-168] minutes per week on average over a one year period. Over a time period of 18 months, Bovens et al\textsuperscript{9} reported 12.1, 10.0, and 7.0 injuries per 1000 hours of running among marathon runners who ran 162, 192, and 240 minutes per week. Buist et al\textsuperscript{15} found an average of 33 [95\% CI: 27-40] RRI per 1000 hours of running in two groups of novice runners. One group was instructed to run an average of 52 minutes per week over a 13 week period (30 RRI/1000 hours), while the other group were instructed to run an average of 59 minutes per week over a 8 week period (38 RRI/1000 hours). Figure 2 shows the RRI/1000 hours of running in groups running different minutes per week.

Buist et al\textsuperscript{15} investigated the relationship between weekly progression in running duration and likelihood of injury. There was no significant difference in the incidence of RRI in a group of runners with a 13 week training program with a mean duration increase of 10\% per week compared to the incidence of RRI in a group of runners training an 8 week training program with a mean duration increase of 24\% per week. However, although not significant, the mean survival time of runners in the 13 week training group was 212 minutes, compared to 167 minutes in runners of the 8 week training group.

**Intensity**

In fourteen studies, the relationship between training intensity and development of RRI was investigated.\textsuperscript{1,4,11,13,14,17,63-70} Jacobs et al\textsuperscript{13} found a pace above 8 min/mile to increase the risk of injury as compared with a pace below 8 min/mile (p<0.05). Hootman et al\textsuperscript{4} found a reduced odds ratio (0.51 [0.35, 0.74]) for sustaining an injury among males who ran at above a 15 min/mile pace compared to those who ran at a faster pace (p=0.0004). A similar significant difference was found for female subjects (p≤0.05). However, lack of adjustment for other predictor variables such as weekly mileage weakened this association. This is supported by Marti et al,\textsuperscript{14} who found that running speed calculated from 10 mile race time was positively related to injury incidence in univariate analysis, but adjustment for mileage clearly weakened this association. In eight studies, no significant relationship between average training pace and likelihood of injury were found.\textsuperscript{1,11,17,63-66,68} Wen et al\textsuperscript{63,69} reported that no association was found between running pace and injury. However, it was reported that interval training increased the risk of shin injury (p<0.05).\textsuperscript{63} In a case-control study, Messier et al\textsuperscript{67} found runners with iliotibial band friction syndrome to run on average 3 seconds/mile faster than the control group during non-competition training (p = 0.05). McCrory et al\textsuperscript{70} found training pace to be a significant (p≤0.05) discriminator between persons with achilles tendinitis when they examined pace in minutes per kilometer, where the pace of those injured was 4.64 ± 0.08 as compared to controls which was 4.87 ± 0.07.

<table>
<thead>
<tr>
<th>Study</th>
<th>Comparison</th>
<th>Subgroup</th>
<th>MINUTES PER WEEK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bovens</td>
<td>RRI / 1000 hrs</td>
<td>Marathoners</td>
<td>0  30  60 120 180 240 300</td>
</tr>
<tr>
<td>Jakobsen</td>
<td>RRI / 1000 hrs</td>
<td>Marathoners Int.</td>
<td>7.4 10.0 12.1</td>
</tr>
<tr>
<td>Jakobsen</td>
<td>RRI / 1000 hrs</td>
<td>Marathoners Con.</td>
<td>7.0 10.0 12.1</td>
</tr>
<tr>
<td>Buist</td>
<td>RRI / 1000 hrs</td>
<td>Novice (13 week)</td>
<td>7.0 10.0 12.1</td>
</tr>
<tr>
<td>Buist</td>
<td>RRI / 1000 hrs</td>
<td>Novice (8 week)</td>
<td>7.0 10.0 12.1</td>
</tr>
</tbody>
</table>

**Figure 2.** Relation between minutes per week and number of Running Related Injury (RRI) per 1000 hours of running. Results from the articles by Bovens and Jakobsen are calculated based on figures in the articles. Int = intervention. Con = controls. RRI = Running Related Injury. Hrs = Hours.
The relationship between training frequency and development of RRI was investigated. Results are presented in Figure 3. In six articles, RRIs in general were investigated; one investigated front thigh injuries, and one shin splint. In several studies, an increased risk, relative risk, or odds ratio for sustaining an RRI was reported when the weekly running frequency increased. Persons running 6-7 times per week had the highest risk. On the contrary, Taunton et al found an increased risk of injury among females running one time per week. Males also showed a similar trend, although it was not statistically significant (p = 0.064). Satterthwaite et al found the odds ratio for sustaining an anterior thigh injury increased by 1.19 [1.05-1.34] per one day increment in running frequency. No significant association was found for hamstring, hip, knee, or calf injuries. Knobloch et al reported an increased risk of shin splints among individuals running more than five days per week.

**DISCUSSION**

The purpose of this study was to investigate the relationship between training characteristics and running related injuries using a systematic review of the literature. Training characteristics were categorized into four groups: volume, duration, intensity, and frequency. The majority of the included prospective studies had a higher methodological quality when compared with the case-control studies and cross sectional studies.

**Frequency**

In eight articles, the relationship between training frequency and development of RRI was investigated. Results are presented in Figure 3. In six articles, RRIs in general were investigated; one investigated front thigh injuries, and one shin splint. In several studies, an increased risk, relative risk, or odds ratio for sustaining an RRI was reported when the weekly running frequency increased. Persons running 6-7 times per week had the highest risk. On the contrary, Taunton et al found an increased risk of injury among females running one time per week. Males also showed a similar trend, although it was not statistically significant (p = 0.064). Satterthwaite et al found the odds ratio for sustaining an anterior thigh injury increased by 1.19 [1.05-1.34] per one day increment in running frequency. No significant association was found for hamstring, hip, knee, or calf injuries. Knobloch et al reported an increased risk of shin splints among individuals running more than five days per week.

**Volume and duration**

Previously, several authors proposed that a high weekly mileage is associated with an increased risk of sustaining RRI. This is generally supported by the findings from the current systematic review. However, Fields et al questions the reliability of mileage as an injury predictor, since they found injured runners averaging essentially the same mileage as healthy runners. According to Jakobsen et al, it is therefore correct to use the incidence (injury per time) for comparison purposes because the risk of injury must be related to the time spent engaged in running. When injuries are related to exposure time, expressed as 1000 hours of exercise, Bovens et al found that the number of injuries decreased when weekly mileage during an 18 month period increased from 15 miles per week to 37 miles per week. The assumption that injury incidence is decreased when running greater distances is supported in other studies which investigated injury incidence among runners training different mileages per week. In the study by Bovens et al,
the mileage increase was accompanied by maturation as a runner, which possibly can explain the reduced risk of injury as weekly mileage increase; experienced runners may know the injury threshold better than novice runners. If this is the case, maturation as a runner would have to be considered an uncontrolled, confounding factor. The incidence is reported from 2.5 to 7.4 injuries per 1000 hours of exercise among marathon runners, while injury incidence per 1000 hours of running among novice runners who trained 30 to 90 minutes per week is 33. Based on these findings, a hypothetical example of the number of RRI over a 26 week period can be calculated for novice and marathon runners. If novice runners run for 30 minutes 3 times per week over 26 weeks they will run 39 hours in total. Taking into account the risk of injury of 33 per 1000 hours of running reported by Buist et al, the novice runner will sustain 1.29 injuries when running 39 hours. Similarly, marathon runners with the risk of 7.4 RRI per 1000 hours of running reported by Jakobsen et al can expect 1.15 injuries if they run 156 hours (2 hours 3 times per week) over the same period of time. In this hypothetical example, the absolute numbers of injuries would be higher among novice runners. This is consistent with the findings by Walter et al who stated that the risk of injury per mile of training declines with total mileage, so the small absolute increment in risk associated with increasing mileage may be acceptable to many athletes. All in all, these findings suggest that the relative injury threshold becomes higher in runners with higher weekly mileage.

In overview articles, authors have suggested a maximal increase of weekly volume of no more than 10% per week, the so called “10% rule”, in order to reduce the risk of injury. This suggests that runners who increase the weekly volume by less than 10% have reduced risk of RRI when compared with runners whose weekly increase is above 10%. In a randomized controlled trial by Buist et al, the 10% rule was tested in novice runners. No significant difference in injury rates were found between runners following a graded training program with an increase in weekly duration of 10.5% compared to runners with an increase in weekly duration of 23.7%. However, it must be noted that both groups had a progression rate above 10%. If runners with a progression rate below 10% per week were compared with runners who increase their weekly volume for instance 40–60%, a statistically significant difference in injury rates may be shown. However, it may be unethical to conduct a randomized controlled trial with the intervention group having an increase in weekly mileage above 40%. In the study by Taunton et al, all runners had to participate in one weekly training session. The length of this weekly training session was increased every week. An increased risk of injury was found among females who only participated in one training session compared to runners who ran more training sessions per week. Although not significant, a similar trend was found for males. Taunton et al suggest that it stands to reason that a person who does not build an adequate training base during the other weekly training sessions will be more likely to be injured when they participate in a program that steadily increases in volume. However, information on progression rates were not reported in the study by Taunton et al, and because of this it is not possible to relate the results to the 10% rule.

In conclusion, there is some evidence suggesting weekly mileages to be associated with injury. However, the relative injury threshold becomes greater in runners with higher weekly mileage. Clearly, more studies must be conducted to investigate the link between weekly increase in running volume and development of RRI, taking into account the influence of intensity, duration, and frequency.

**Intensity**

The literature showed conflicting results with regard to training intensity and development of injuries. Thus, the way of assessing and reporting training pace may be the reason for inconsistent results. In all included studies, training intensity was measured subjectively by assessing the self-reported running pace. This may be a major problem, since self-reporting may be affected by recall bias. Furthermore, the participants only reported the average pace. The variation in training pace within and between sessions is therefore not accounted for. Thus, the variation in training intensity is likely unknown and may or may not play a role in the relationship between training intensity and risk of RRI. One possible solution is to measure the training intensity objectively or quasi-objectively in each training session. To date, no studies were found that described a quasi-objective measure such as perceived exertion or other objective measures of training in relationship to

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injury. Again, more studies have to be conducted to ascertain if there is a relationship between training intensity and development of injury.

**Frequency**

A “U-shaped” pattern between frequency and development of RRI may exist: Taunton et al. found an increased risk of injury among female runners training one time per week. While McKean et al., Jacobs et al., Macera et al., and Walter et al. reported an increased risk among runners training 6-7 times per week compared with those training 2-5 times per week. Based on this, one might conclude that the ideal frequency is 2-5 running sessions per week. However, in the studies by Macera et al. and Walter et al. no additional risk was found after controlling for running volume. Therefore, Brill and Macera suggested that cumulative distance is a better indicator of injury risk than the lack of rest between runs. Thus, based on all the studies included in this review it must be concluded that it is not possible to determine the specific role of running frequency with regard to injury.

**Running experience**

The experience of the runners included in the different studies may bias the results, since the included studies include a wide variety of types of runners. Jakobsen et al. and Marti et al. reported that experience was an important factor for injury risk, because high running experience diminished the risk of injury. In the study by Buist et al. novice runners reported the highest number of RRIs per 1000 hours of running. This was supported by Macera et al. who reported new runners to be at greater risk for injury than more experienced runners. Perhaps habitual and experienced runners know their own injury threshold better as compared to novice runners and are therefore less likely to sustain RRI. This may seem to lead to the conclusion that novice runners have greater risk of injury. However, novice runners may be more likely to report injuries compared to experienced runners who, in many cases, have sustained several injuries previously and therefore do not consider some conditions or pain severe enough to classify them as injuries.

**Definitions of Running Related Injury**

In the study by Mechelen et al. no attempt was made to compare the injury patterns between studies because of the differences in definitions and research methods, as well as research outcome. A similar problem exists in the current systematic review. In Table 3 the different injury definitions used in the 30 studies included was presented. There is a large variation in injury definition and it must be questioned if the different definitions of RRI in the studies included in this review are comparable. In their review, Ryan et al. stated that a standardized definition of running injury would benefit the understanding of injury prevalence, and can ultimately assist in injury prevention. Additionally, Satterthwaite et al. and Reinking et al. question the validity and reliability of measuring injury by self-reporting, as this method of describing RRI may be affected by subject recall bias.

**Measurement of training characteristics**

The methods used to collect information on exposure data are very similar. In all studies included in this review, questionnaires, surveys, or self-report diaries were used to collect information on training exposure. In this regard, several authors have concluded that the training exposure may have been estimated or reported incorrectly again due to recall bias. Therefore, the methods used in all studies to measure training exposure by subjective measurements (questionnaires, surveys, diaries) should be taken into careful consideration. Methods that utilize technology such as Global Positioning Systems (GPS) and actual distance recording may provide more valid and reliable information on training volume, frequency, and intensity.

**Analysis of training characteristics**

Analysis of training characteristics is complex, since one or more training variable may interact with other training variables. In most papers included in the current review, only the crude association between a single training variable and the risk of injury was investigated, without accounting for the confounding or modifying effect of other training variables. Volume and duration are two partially independent variables. Running intensity is dependent on volume and duration, since intensity is volume divided by duration. Since volume, duration, and intensity all affect one another it may be relevant to measure and analyze all three variables. Since it seems likely that the relationship between the exposure variable and RRI may
depend on the level of other training variables, future studies should allow for such comparisons. Furthermore, the frequency should be included in the analysis even though it is not directly linked with volume, duration, or intensity. This approach is supported by Buist et al who stated that the increase of running duration, intensity, and frequency should be taken into careful consideration. Hootman et al investigated the relationship between an exposure variable and the risk of RRI while adjusting for other training related variables. However, it was not mentioned which training variables were adjusted for. Walter et al used a better approach by described the training variables which were adjusted for. An increased risk of injury was found among those performing interval training. However, the association was considered unimportant once the result was adjusted for the effect of total training volume. Another example was in the study Marti et al. In this study, running speed was positively related to injury in univariate analysis, but again adjustment for mileage clearly weakened this association. The approaches used by Walter et al and Marti et al are clear examples of authors trying to take into account the interactions between several training variables. It must be emphasized that the analysis of training characteristics should use, to some extent, the same assumption: that training variables are related and affect each other. Based on this, the current approaches used to analyze exposure data in order to investigate the relationship between training characteristics and RRI in a majority of the reviewed articles must be taken into careful consideration when the results are interpreted. In future studies the interaction between running volume, duration, intensity, and frequency must be considered.

Data may also have to be analyzed differently than it has been previously, especially if training variables are measured by GPS or other objective methods. Since data from GPS measurements are extensive they could be analyzed in a variety of ways. For example variability between training sessions or variations within sessions could be analyzed in addition to sudden increases in one or more training variables. Based on their measurements Wen et al stated, that the possibility to examine for sudden increases in training variables was limited. This may be a key point, since it has been suggested that a sudden increase in running duration or intensity can overwhelm the ability for adaptive change, tissue repair, and result in injury. The lack of ability to objectively measure such increases defined as “sudden” may affect the possibility to investigate the relationship between training exposure and RRI, since Jacobs et al reported that one third of those injured described they had changed their training just prior to their injuries. Although it is not possible to examine this statement based on articles included in this review, an interesting focus for future research would be to investigate if the sudden increase in one or more training variables, as suggested by many, is more strongly related to injury than the absolute volume which is currently suggested to be the main contributor to injury. It must be emphasized that there is a strong need for future studies regarding RRI with the primary purpose of investigating the link between training characteristics and the development of RRI.

CONCLUSION

Based on the studies reviewed it was not possible to identify which training errors are related to running related injuries. Running experience and injury threshold seem to play a role in the relationship between training characteristics and development of injuries, while volume, duration, intensity, and frequency seem to have a complex interaction with each other which is not accounted for in the majority of the included studies. All training variables should be measured and accounted for when studies on the relationship between training characteristics and injuries are examined in future studies. If methodological limitations can be solved by objectively measuring the training characteristics more studies can be conducted to carefully define training variables and their interactions, and then plan a large scale prospective study or randomized controlled trial to determine whether cause and effect relationships exist.

REFERENCES


APPENDIX 1: SEARCH TERMS

("Running"[Mesh] OR (foot race)) AND ("Exercise"[Mesh] OR exposure OR "Physical Therapy Modalities"[Mesh] OR "Clinical Protocols"[Mesh] OR (regim*) OR program OR programme OR "Healthy People Programs"[Mesh] OR marathon OR marathon OR training OR (training characteristics) OR (running patterns) OR volume OR intensity OR frequency OR speed OR pace OR distance OR mileage) AND (injur* OR syndrome* OR tendin* OR fractur* OR ("pain"[Mesh]) OR fasciitis OR bursitis OR splint* OR tear* OR sprain* OR strain* OR entrapment* OR ostei* OR osteopor* OR osteoa* OR rupture* OR arthros* OR arthri* OR lipoma OR sciatica OR lumbago OR laceration* OR split* OR tenosynovitis OR blister* OR cramp* OR corn OR callus* OR edema* OR sesamoiditis OR ganglion* OR hernia* OR muscle soreness OR delayed onset muscle soreness OR hemorrh* OR ischi* OR neuroma* OR abrasion OR wart* OR mold* OR dislocation* OR damage OR trauma OR displacement OR periostitis) NOT ("addresses"[Publication Type] OR "bibliography"[Publication Type] OR "biography"[Publication Type] OR "case reports"[Publication Type] OR "clinical conference"[Publication Type] OR "comment"[Publication Type] OR "congresses"[Publication Type] OR "directory"[Publication Type] OR "editorial"[Publication Type] OR "festschrift"[Publication Type] OR "government publications"[Publication Type] OR "interview"[Publication Type] OR "lectures"[Publication Type] OR "legal cases"[Publication Type] OR "legislation"[Publication Type] OR "letter"[Publication Type] OR "news"[Publication Type] OR "newspaper article"[Publication Type] OR "retracted publication"[Publication Type] OR "retraction of publication"[Publication Type] OR "review"[Publication Type] OR "scientific integrity review"[Publication Type] OR "technical report"[Publication Type] OR "twin study"[Publication Type] OR "validation studies"[Publication Type] OR pregnancy OR rugby OR soccer OR football OR rheumatoid)
ABSTRACT

Background: Achilles tendinopathy (AT) is a common pathology and the aetiology is unknown. For valid and reliable assessment The Victorian Institute of Sports Assessment has designed a self-administered Achilles questionnaire, the VISA-A. The aim of the present study was to evaluate VISA-A as an outcome measure in patients with AT.

Methods: A systematic search of the literature was conducted using MEDLINE, EMBASE, CINAHL, PEDro, Web of Science, and Cochrane Controlled trials to identify trials using VISA-A for patients with AT. This was followed by data mining and analysis of the obtained data.

Results: Twenty-six clinical trials containing 1336 individuals were included. Overall mean VISA-A scores ranged from 24 (severe AT) to 100 (healthy). Mean VISA-A scores in patients with AT ranged from 24 to 96.6. Healthy subjects scored a minimum of 96. Only two groups of participants from two different studies had a post-VISA-A score as high as healthy individuals, indicating full recovery of the AT.

Conclusions: A VISA-A score lower than 24 is rarely attained in AT. Only few patients with AT reach an equivalent VISA-A score compared to uninjured healthy subjects following treatment. The VISA-A is a reliable tool when assessing AT patients, providing a good assessment of the actual condition from very poor, (score around 24) to excellent (a score of 90), which based on this systematic review and previous studies could be considered full recovery from AT.

Key Words: Achilles tendinopathy, outcome measure, reliability, VISA-A.
BACKGROUND

Achilles tendinopathy (AT) is a common overuse injury, especially among athletes, but also in non-athletes. AT often becomes chronic. The incidence of AT has been rising over the past three decades and the aetiology is considered to be multi-factorial. Despite the high incidence, the aetiology of AT remains undiscovered making prevention and treatment difficult. With lack of objective measurements of AT severity, the patient-reported Victorian Institute of Sports Assessment (VISA-A) is used for assessment of physical disability due to AT as an outcome measure based on symptoms.

The typical clinical finding of AT is pain in the midportion of the Achilles tendon, especially produced by physical activity. As a result of pain AT often causes a reduction in function and activity level with a negative impact on general health and well-being. AT is a clinical diagnosis, and use of power Doppler ultrasound (PDU) for assessment may reveal neovascularisation in patients with AT, providing the ability to offer both diagnostic and monitoring information. Neovascularisation is, on the other hand, not directly related to the patient’s symptoms of pain.

Due to the multi-factorial aetiology of AT, health-care providers often resort to multiple approaches to manage the symptoms. When AT is diagnosed, conservative intervention, often including eccentric exercise, is preferred over surgical treatment. The aim of all treatment being restoration of patient function to a desired level of physical activity.

Randomised controlled studies (RCTs) try to compare interventions or compare an intervention with placebo. It is difficult to compare the interventions of the various RCTs if the applied outcome measures vary widely and there is not a clear outcome measure. One standardised measure of AT severity which may be used to compare studies, both as a guideline for treatment and for monitoring treatment outcomes, is the VISA-A. In addition to the VISA-A, other outcome measures like the Foot and Ankle Outcome Score (FAOS), clinical tests using ultrasonography and pressure algometry, and visual analogue scoring (VAS) of Achilles tendon pain, have been suggested. Even though a conclusive method of assessment is yet to be found, the self-administered questionnaire the VISA-A, measuring the severity of AT by evaluating pain, function and effect on activity, is at present considered first choice. The VISA-A has been shown to be sensitive to clinical changes and is easily comprehensible to patients, as well as being relevant to clinicians. As a standardised outcome measure, the VISA-A has proven to be a both reliable and valid instrument as shown in the studies where VISA-A has been validated and translated into Dutch, Turkish, German, Italian, and Swedish.

The VISA-A is based on an inverted numeric rating scale (NRS) and results in a score range from 0 to 100 points with asymptomatic persons expected to score 100 points. A symptomatic person with severe AT would, on the other hand, be expected to score significantly lower. The VISA-A score is not divided into subgroups, rather it rates the overall effect of AT on a number of activities involving the Achilles tendon. In this systematic review the authors investigated the use of the VISA-A as a measure of the severity of symptoms in AT and as a tool to monitor the change in symptoms and function following interventions provided for the treatment of AT. The aim was to determine the range of the VISA-A scores in a wide range of AT patients, and in healthy individuals. Furthermore, the authors wished to investigate if AT patients after rehabilitation would obtain a VISA-A score comparable to those found in healthy subjects.

The aim of this systematic review was to determine the range of the VISA-A scores reported for varying grades of AT, as well as those reported for healthy subjects, and thereby define the possible limitation of this tool when assessing various rehabilitation schemes, and when defining the score range for healthy controls.

METHODS

A comprehensive, structured literature search was performed. Data mining of selected studies and data analysis were then performed.

Literature Search

The following bibliographic databases were searched: MEDLINE via PubMed from 1950, EMBASE via OVID from 1980, CINAHL via EBSCO from 1981, PEDro, Web of Science from 1900, and The Cochrane Central Register of Controlled Trials, each until July 2011.

The following search terms were used: (tendinopathy OR tendonitis OR tendinosis OR achilles*) AND VISA*
used as keywords (where possible) as well as text words. No limitations to the searches were applied. Reference lists of selected studies were also searched for possible additional appropriate studies.

Inclusion criteria
Trials were included for analysis if they met the following three selection criteria:

1. The study population consisted of men and/or women aged ≥18 years with a diagnosis of chronic non-insertional Achilles Tendinopathy (AT) and/or healthy controls concerning AT
2. Possible intervention was contained in the professional domain of the general-practice physical therapist/medical doctor and included different types of acknowledged treatments of AT
3. The study used the VISA-A as an outcome measure

Data mining and Analysis
Two reviewers (JVI + EMB) independently evaluated all articles for eligibility. Disagreements were resolved by discussion.

Extraction of data from the included trials was carried out independently by reviewers (JVI + EMB). Trials were divided into two groups regarding presence or absence of intervention. The core outcome data in each trial was given as a mean VISA-A score and SD, or range of VISA-A score. Some studies did not give SD or range (marked with * in table 1).

RESULTS
Selection
The systematic literature search resulted in the identification of 68 studies. The selection process is shown figure 1.

Out of the 68 studies, 33 studies (49%) were excluded on the basis of the title and the content of the abstract, the main reasons for exclusion being diagnosis e.g. Patellar tendinopathy or insertional Achilles tendinopathy, or not using the VISA-A questionnaire. Two studies were excluded on the basis of an unclear diagnosis.20,21 The remaining studies were scrutinized, and 9 additional studies were excluded due to not using or publishing a VISA-A score (k = 5). Also a study protocol, a synopsis, and a two single case studies were excluded (k = 4). Finally the remaining 26 trials3,5,15-19,22-40, representing 46 different groups of individuals, 39 groups of patients with AT and 7 groups of healthy individuals, were included (Figure 1). These trials were separated into interventional and non-interventional studies and their characteristics are summarized in Tables 1 & 2.

Study characteristics
Overall, the included trials had a total number of participants ranging from n = 513 to n = 4532. In the studies testing an intervention, the number of included subjects ranged from n = 143 to n = 873. The subjects (n = 1336) in the 26 trials consisted of athletes as well as of non-athletes. Altogether 281 healthy individuals and 1055 AT patients were included.
In the included studies, the duration of mid-portion Achilles tendon pain ranged from 6 to 26 weeks. Specifications like pain in the morning, pain that impaired performance, and pain on palpation, varied among trials. In most trials, non-insertional tendinopathy was defined as pain located in the area from 2 to 7 cm (a few trials from 2 to 6 cm) proximal to the insertion on the Calcaneus bone. All of the trials

<table>
<thead>
<tr>
<th>Studies</th>
<th>Participants</th>
<th>Intervention</th>
<th>Pre-VISA-A</th>
<th>Post-VISA-A</th>
</tr>
</thead>
<tbody>
<tr>
<td>de Vos et al. 2010</td>
<td>PRP (n=27)</td>
<td>24 weeks of EE</td>
<td>PRP: 46.7(16.2)</td>
<td>PRP: 68.4(22.1)</td>
</tr>
<tr>
<td></td>
<td>Ctrl (n=27)</td>
<td></td>
<td>Ctrl: 52.6(19.0)</td>
<td>Ctrl: 73.1(22.5)</td>
</tr>
<tr>
<td>Gaweda et al., 2010</td>
<td>AT (n=15)</td>
<td>PRP, Follow-up; 18 months</td>
<td>24(8-31)</td>
<td>96(80-100)</td>
</tr>
<tr>
<td>McAleenan et al. 2010</td>
<td>NS (n=5)</td>
<td>12 weeks of EE</td>
<td>NS: 67.8(19.9)</td>
<td>NS: 96.6 (33.1)</td>
</tr>
<tr>
<td></td>
<td>Ctrl (n=6)</td>
<td></td>
<td>Ctrl: 42.7(16.1)</td>
<td>Ctrl: 64.0 (21.4)</td>
</tr>
<tr>
<td>Silbernägel et al. 2010</td>
<td>AT (n=34)</td>
<td>12 weeks to 6 months of EE Follow-up; 5 years</td>
<td>56(16)</td>
<td>90(11)</td>
</tr>
<tr>
<td>Humphrey et al. 2009</td>
<td>Athletes (n=11)</td>
<td>HVIGI with steroid Mean follow-up; 2.9 weeks</td>
<td>46.3(15.1)</td>
<td>84.1(10.6)</td>
</tr>
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<td>Rompe et al. 2008</td>
<td>SWT (n=34)</td>
<td>12 weeks of EE Follow-up; 4 months</td>
<td>SWT: 50.2(11.1)</td>
<td>SWT: 86.5(16.0)</td>
</tr>
<tr>
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<td>Ctrl (n=34)</td>
<td></td>
<td>Ctrl: 50.6(10.3)</td>
<td>Ctrl: 73.0(19.0)</td>
</tr>
<tr>
<td>de Jonge et al. 2008</td>
<td>NS (n=30)</td>
<td>12 weeks of EE Follow-up; 1 year</td>
<td>NS: 49.2*</td>
<td>NS: 78.2*</td>
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<td>Ctrl (n=32)</td>
<td></td>
<td>Ctrl: 50.1*</td>
<td>Ctrl: 75.7*</td>
</tr>
<tr>
<td>Maffulli et al. 2008</td>
<td>Athletes (n=45)</td>
<td>12 weeks of EE</td>
<td>36(23.8)</td>
<td>52(27.5)</td>
</tr>
<tr>
<td>Chan et al. 2008</td>
<td>AT (n=30)</td>
<td>HVIGI with steroid Mean follow-up; 30.3 weeks</td>
<td>44.8(17.7)</td>
<td>76.2(24.6)</td>
</tr>
<tr>
<td>Knobloch et al. 2008</td>
<td>Male (n=38)</td>
<td>12 weeks of EE</td>
<td>Male: 63(12)</td>
<td>Male: 86(13)</td>
</tr>
<tr>
<td></td>
<td>Female (n=25)</td>
<td></td>
<td>Female: 60(14)</td>
<td>Female: 75(11)</td>
</tr>
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<td>Tumilty et al. 2007</td>
<td>LLLT (n=10)</td>
<td>12 weeks of EE</td>
<td>LLLT: 57(16.7)</td>
<td>LLLT: 82.2</td>
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<td></td>
<td>Ctrl (n=10)</td>
<td></td>
<td>Ctrl: 56.3(19.8)</td>
<td>Ctrl: 77.5</td>
</tr>
<tr>
<td>de Vos et al. 2007</td>
<td>PDU(0) (n=23)</td>
<td>12 weeks of EE</td>
<td>PDU(0): 55*</td>
<td>PDU(0): 74*</td>
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<tr>
<td></td>
<td>PDU(1-4) (n=40)</td>
<td></td>
<td>PDU(1-4): 47*</td>
<td>PDU(1-4): 65*</td>
</tr>
<tr>
<td>Silbernägel et al. 2007</td>
<td>CA (n=19)</td>
<td>6 weeks of CE and EE Follow-up; 1 year</td>
<td>CA: 57(15.8)</td>
<td>CA: 85(12.7)</td>
</tr>
<tr>
<td></td>
<td>SA (n=19)</td>
<td></td>
<td>SA: 57(15.7)</td>
<td>SA: 91(8.2)</td>
</tr>
<tr>
<td>de Vos et al. 2007</td>
<td>NS (n=31)</td>
<td>12 weeks of EE</td>
<td>NS: 49.4*</td>
<td>NS: 67.0*</td>
</tr>
<tr>
<td></td>
<td>Ctrl (n=32)</td>
<td></td>
<td>Ctrl: 50.1*</td>
<td>Ctrl: 68.8*</td>
</tr>
<tr>
<td>Silbernägel et al. 2006</td>
<td>AT (n=25)</td>
<td>6 months of CE and EE Follow-up; 1 year</td>
<td>AT: 56(16.5)</td>
<td>AT: 89(10.6)</td>
</tr>
<tr>
<td></td>
<td>Healthy (n=25)</td>
<td></td>
<td>Healthy: 99.8(0.8)</td>
<td>Healthy: 100(0)</td>
</tr>
<tr>
<td>Sayana et al. 2006</td>
<td>Non-athletes (n=33)</td>
<td>12 weeks of EE</td>
<td>39 (22.8)</td>
<td>50 (26.5)</td>
</tr>
<tr>
<td>Brown et al. 2006</td>
<td>Aprot (n=15)</td>
<td>12 weeks of EE</td>
<td>Aprot: 59.1*</td>
<td>Aprot: 95.4*</td>
</tr>
<tr>
<td></td>
<td>Ctrl (n=18)</td>
<td></td>
<td>Ctrl: 62.2*</td>
<td>Ctrl: 94.5*</td>
</tr>
<tr>
<td>Lakshmanan et al. 2004</td>
<td>AT (n=16)</td>
<td>SWT, Follow-up; 20 months</td>
<td>46.6(11.3)</td>
<td>75.9(19.1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total studies</th>
<th>Total (n=709)</th>
</tr>
</thead>
</table>

PRP= Platelet-rich plasma injections; Ctrl= Controls; EE= Eccentric exercise; HVIGI= High volume image guided injections; NS= Night splint; LLLT= Low level laser therapy; SWT= Shock wave therapy; PDU= Power Doppler ultrasound; CE= Concentric exercise; Aprot= Aprotinine injections; CA= Continued activity; SA= Stopped activity; *Lack of SD or range
included both men and women. Age of the included subjects ranged from 18 to 70 years.

**VISA-A mean scores in interventional studies (Table 1)**

The author’s identified 18 studies with a total of 684 AT patients. In all interventional studies a significant improvement, as operationally defined by the authors in each study, in VISA-A score was demonstrated following treatment (Table 1). A variety of interventions were used in the treatment of AT, with 14 of the 18 included studies (78%) using at least eccentric exercise (EE) in the rehabilitation regime (Table 1). The specific interventions used in the trials are described in Table 1. Pre-treatment mean VISA-A scores for AT patients ($n=684$) ranged from $24^{28}$ to $63^{39}$. Post-treatment mean VISA-A scores for AT patients ($n=684$) ranged from $50^{35}$ to $96.6^{39}$. Improvement in VISA-A score following treatment ranged from $11^{35}$ to $72^{22}$ points. Follow-up time ranged from 2.9 weeks$^{29}$ to 5 years$^{39}$.

The VISA-A score prior to and following intervention was plotted in a diagram to visualise the present use of VISA-A as an outcome measure in the included studies (Figure 2).

### Table 2. Non-interventional studies using VISA-A ($n=8$). Total number of participants is 627. VISA-A score is given with SD or range. In studies where two VISA-A scores were published regarding reliability, only the first VISA-A score was plotted.

<table>
<thead>
<tr>
<th>Studies</th>
<th>Participants</th>
<th>VISA-A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peers et al. 2002</td>
<td>AT ($n=25$)</td>
<td>AT: $54^{12-92}$</td>
</tr>
<tr>
<td>Silbernägel et al. 2006</td>
<td>AT, LS ($n=42$)</td>
<td>LS: $57^{15.7}$</td>
</tr>
<tr>
<td></td>
<td>AT, MS ($n=42$)</td>
<td>MS: $87^{19.8}$</td>
</tr>
<tr>
<td>Lohrer et al. 2009</td>
<td>AT, C ($n=15$)</td>
<td>C: $73.1^{13.5}$</td>
</tr>
<tr>
<td></td>
<td>AT, P ($n=15$)</td>
<td>P: $44.9^{14.2}$</td>
</tr>
<tr>
<td></td>
<td>HC, J ($n=31$)</td>
<td>J: $99^{2}$</td>
</tr>
<tr>
<td></td>
<td>HC, S ($n=48$)</td>
<td>S: $98^{7}$</td>
</tr>
<tr>
<td>Dogramaci et al. 2009</td>
<td>AT ($n=55$)</td>
<td>AT: $52.9^{13.6}$</td>
</tr>
<tr>
<td></td>
<td>HC ($n=55$)</td>
<td>HC: $97.1^{1.5}$</td>
</tr>
<tr>
<td>Maffuli et al. 2008</td>
<td>AT ($n=50$)</td>
<td>AT: $51.8^{18.2}$</td>
</tr>
<tr>
<td>Silbernägel et al. 2005</td>
<td>AT ($n=51$)</td>
<td>AT: $50^{44-56}$</td>
</tr>
<tr>
<td></td>
<td>HC ($n=15$)</td>
<td>HC: $96^{94-99}$</td>
</tr>
<tr>
<td>Robinson et al. 2001</td>
<td>AT, NS ($n=45$)</td>
<td>NS: $64^{59-69}$</td>
</tr>
<tr>
<td></td>
<td>AT, PS ($n=14$)</td>
<td>PS: $44^{28-60}$</td>
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<td></td>
<td>HC ($n=87$)</td>
<td>HC: $96^{94-99}$</td>
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<tr>
<td>de Knikker et al. 2008</td>
<td>AT ($n=17$)</td>
<td>AT: $69^{16.7}$</td>
</tr>
<tr>
<td></td>
<td>HC ($n=20$)</td>
<td>HC: $100^{1.5}$</td>
</tr>
</tbody>
</table>

8 studies | Total ($n=627$) |

LS = Least symptomatic; MS = Most symptomatic; C = Conservatives; P = Pre-operatives; J = Joggers; S = Students; HC = Healthy controls; NS = Non-surgical; PS = Pre-surgical
VISA-A scores in non-interventional studies (Table 2)

Eight non-interventional studies, mostly validity or reliability studies, with 371 subjects looked at VISA-A scores in AT patients. In these studies mean VISA-A scores ranged from 44 to 87.19 Included were the original English VISA-A validation along with the German, Turkish, Italian, Swedish, and the Dutch translations and adaptations of the VISA-A questionnaire.

VISA-A measuring healthy individuals

5 non-interventional3,15-17,19 and one interventional study38 contained information of VISA-A scores in 281 healthy individuals. Overall, healthy individuals showed a mean VISA-A score ranging from 963,19 to 100.15

VISA-A measuring AT severity

The mean VISA-A scores for all AT patients in both interventional and non-interventional studies (26 trials), representing altogether 39 groups and 1055 participants, ranged from 24 to 96.33

The mean VISA-A score range for both AT patients and healthy individuals based on the present studies ranged from 24 to 100.15

Only two studies reported some AT patients following intervention with a score of 96 or higher, approaching scores reported for healthy subjects (Table 1).28,33 Patients in these studies had mean VISA-A scores of 9628 and 96.6.33

DISCUSSION

The Victorian Institute of Sports Assessment self-administered Achilles questionnaire (VISA-A) was developed as a tool to evaluate the severity of Achilles tendinopathy (AT) and to facilitate comparison of the effect of different rehabilitation regimes regarding symptoms, function and activity in AT patients. The questionnaire has been proven both a valid and reliable instrument.3,15-19 The aim of the current systematic review of the application of VISA-A was to determine the range of the VISA-A scores for all presentations of non-insertional AT as well as in healthy individuals. Furthermore, the authors wished to investigate the possibility of AT patients attaining a VISA-A score as high as healthy individuals, indicating excellent recovery after following rehabilitation.

Application of VISA-A

The results of this systematic review indicate that VISA-A scores in AT patients and healthy individuals, ranged from 24 to 100. This means that patients did not report VISA-A scores under 24 in any study, indicating that scores below a 24 on the VISA-A scale are not normally reported by subjects with AT. An explanation of this phenomenon could be that AT patients usually are able to transport themselves to the clinic, all having some mobility, and this would probably also be the case for the participants in the included studies. To get a score of 0-24, the patient would have to be very disabled, more or less having a ruptured tendon, which could not be characterized as having AT. Based on the present results one may therefore assume that AT patients seen in the clinic would not score lower than 24 on the VISA-A, since the patients recruited to the existing studies have AT and not a tendon rupture.

Since healthy individuals showed a mean VISA-A score of 96 or above, the VISA-A is a useful tool for assessment of patients with AT, since the interval for improvement is large (24-96). There is therefore evidence to support that a healthy subject (i.e. subjects without AT), would report a very high VISA-A score, meaning that the validity of VISA-A should be considered high. Only two studies reported AT patients attaining a score as high as 96 or higher after intervention,28,33 and only one study suggested a VISA-A score value which could be used as indicating the patient having recovered fully. Full recovery was suggested by Yelland et al. as having a VISA-A score of 90 or above,41 which is close to the reported normal range of 96-100 for healthy controls. This is also in accordance with the study with the longest follow-up of 5 years, where the mean VISA-A score was 90 at follow-up.39

In the included studies, scores of 90 or above after intervention may be more likely in studies with a sufficient follow-up period, which was also observed.28,38,39 This can be explained by the likelihood that a continuous increase in VISA-A score ought to occur following successful intervention.42

Success of treatment

Improvement in VISA-A score following treatment ranged from 11 to 72 points. No minimum clinically
important change (MCIC) regarding the VISA-A score has been set so far. Tumilty et al. suggested success as an increase of 20 points,\textsuperscript{40} while other studies used an increase of 12 points as estimated MCIC.\textsuperscript{24,35} With no set agreement on the minimal MCIC for the VISA-A score, and with the wide range found in previous works, an estimated MCIC cannot be set based on this systematic review.

Some of the included studies examined whether there was a correlation between the VISA-A score at baseline and chance of recovery (higher VISA-A score after intervention).\textsuperscript{23,31,35} One of the included studies showed that a higher VISA-A score prior to intervention did not indicate a significantly better prognosis.\textsuperscript{31,35} Furthermore, patients with low VISA-A scores, and hence more severe symptoms, showed the same chance of recovery as patients with an initially higher VISA-A score.\textsuperscript{23,35}

Compatibility of studies

In the included studies, number of participants ranged widely from \( n = 533 \) to \( n = 45 \).\textsuperscript{32} Several studies had a low number of participants, amongst these were 5 interventional studies containing groups with less than 15 participants.\textsuperscript{22,28,29,33,40} These studies with small sample size could suffer from a lack of statistical power.

Furthermore, participants had different previous activity levels, ranging from non-athletes to professional athletes. Since some questions are related to physical activity related to sports participation, and since athletes are more likely to receive a structured rehabilitation and are more motivated to return to their previous activity level,\textsuperscript{33} a better recovery (in VISA points) after intervention is more often seen amongst athletic patients.\textsuperscript{35} However, included studies used the same definition of chronic mid-portion or non-insertional AT based on clinical findings. In all studies, participants had Achilles tendon pain for at least 6 (range of 6–26) weeks and participants of at least 18 (range of 18–70) years of age were included. In most of the studies, 13 (72%) out of 18 studies, eccentric exercise (EE) was used. This is in agreement with current clinical recommendations of use of eccentric exercise for AT.\textsuperscript{7-9}

With a wide range of participants, different previous activity levels, and since some studies gave range and others SD for VISA-A scores, statistical analysis of pooled results was not possible despite an otherwise high homogeneity regarding definition of AT and use of EE in interventional studies. Therefore, only a mean range of VISA-A score was given in this systematic review.

As previously mentioned, some studies had very low numbers of participants.\textsuperscript{22,28,29,33,40}

Furthermore, several studies gave mean VISA-A scores with very wide ranges and SD's, indicating great variation in score between patients.\textsuperscript{32,33} Despite of this, 23 out of 28 interventional studies showed a pre-treatment VISA-A score between 40 and 60 which is far from the proposed score of 90 for recovery. Also 21 out of 28 interventional studies showed a post-treatment VISA-A score of 70 or higher. This gives a wide range for assessing improvement of AT with VISA-A (24-70), and indicates that VISA-A is able to be used to show meaningful changes. Larger sample-size studies with a longer follow-up are needed in the evaluation of VISA-A as a tool for measuring AT.

CONCLUSION

The VISA-A is a robust tool that has been used extensively for initial assessment of and following treatment for AT. Based on this review, a VISA-A score lower than 24 is not attained in patients with AT. A VISA-A score below 60 is usually found in AT patients while healthy individuals will be in the range above 95. Attaining a VISA-A score over 90 could be considered full recovery from AT, based on the results of this systematic review. This is important in the decision of when an AT patient is well enough to participate in physical activity without limitation, however, this proposed cut score for return to function needs to be further researched.

REFERENCES


CASE REPORT

NON-SURGICAL TREATMENT OF A PROFESSIONAL HOCKEY PLAYER WITH THE SIGNS AND SYMPTOMS OF SPORTS HERNIA: A CASE REPORT

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ABSTRACT

Study Design: Case Report

Background: Injury or weakness of lower abdominal attachments and the posterior inguinal wall can be symptoms of a “sports hernia” and an underlying source of groin pain. Although several authors note conservative treatment as the initial step in the management of this condition, very little has been written on the specific description of non-surgical measures. Most published articles favoring operative care describe poor results related to conservative management; however they fail to report what treatment techniques comprise non-operative management.

Case Presentation: The subject of this case report is a professional ice hockey player who sustained an abdominal injury in a game, which was diagnosed as a sports hernia. Following the injury, structured conservative treatment emphasized core control and stability with progressive peripheral demand challenges. Intrinsic core control emphasis continued throughout the treatment progression and during the functional training prior to return to sport.

Outcome: The player completed his recovery with return to full competition seven weeks post injury, and continues to compete in the NHL seven years later.

Discussion: Surgical intervention has been shown to be effective in the treatment of the “sports hernia.” However it is the authors' opinion that conservative care emphasizing evaluation of intrinsic core muscular deficits and rehabilitation directed at addressing these deficits is an appropriate option, and should be considered prior to surgical intervention.

Key Words: groin pain, non-surgical treatment, sports hernia

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BACKGROUND

Groin pain is a common complaint in athletics and a source of frustration for many athletes and clinicians alike. The incidence has been reported as high as 5% of all athletic injuries\(^1\) and often is poorly understood due to its potential complexity of etiologies. In a survey of hockey related injuries, the groin accounted for 15% of all injuries leading to lost competition time.\(^2\) In addition to basic adductor muscle strains, several other structures and conditions have been identified as possible contributors to groin pain/dysfunction. Osteoarthritis of the hip,\(^3\) labral tears and femoroacetabular impingement,\(^4\) osteitis pubis,\(^5,6\) stress fractures of the pubic ramus and femoral neck,\(^7\) various nerve entrapments (including genitofemoral,\(^8\) ilioinguinal,\(^7,9,10\) lateral femoral cutaneous,\(^7,8\) and obturator nerves\(^7,11,12\)) iliopsoas strains and bursitis,\(^7,13\) and intrapelvic pathology are included in a partial list of possible causes. One of the most difficult causes of chronic groin pain to identify is a combination of signs and symptoms referred to as the sports hernia.\(^14,15,16\)

Hackney\(^14\) defined the “sports hernia” as “a weakness of the posterior inguinal wall resulting in an occult (medial) hernia”,\(^14,15,17,18\) but recently this definition has expanded to more broadly include injuries to the abdominal wall and supporting musculature (Figure 1).

Some authors have noted a correlation between the sports hernia with other muscular injuries about the pelvis, most commonly injuries of the adductors.\(^17,18,19\) It has also been suggested that this injury occurs bilaterally\(^14,19\) and is related to kinematics of the trunk, pelvis and lower extremities. The prevalence of this injury has been shown to be higher in sports that involve cutting, pivoting, and quick powerful changes in direction such as soccer, ice hockey and football\(^17,18,19\). In one report sports hernia was noted to be the underlying cause in as high as 50% of athletes with chronic groin pain.\(^20\)

Subjective histories involving the onset of groin pain vary depending on the activity of the athlete and the circumstances surrounding the injury. Injury can occur from a specific incident usually associated with cutting and planting of the lower extremities at speed or with contact activities.\(^17,19\) However most often groin pain is of a chronic nature,\(^8,14,17,18,20,21,22,23,24\) occurring insidiously and is related to repetitive stresses incurred across the pelvis and associated muscular attachments.\(^14,17,18\) Common subjective symptoms may include pain with strenuous activity, resolution of or minimal pain with rest, and unilateral or bilateral inguinal and adductor pain.\(^18,19\)

Objective clinical findings rarely include a palpable hernia.\(^19,25,26\) However, palpation can include tenderness of the lower abdominal/inguinal ligament region,\(^15,18,19,25,26\) pubic tubercle,\(^14,15,18,25\) pubic symphysis,\(^14,19,27\) and the adductor muscles of the thigh.\(^15,18,19\) In addition, pain may be elicited with stretch of the adductors, resisted hip adduction, and the sit-up maneuver, due to contraction of the rectus abdominis.\(^15,15\) Hölmich et al\(^28\) evaluated the intra-observer and inter-observer reliability of nine examination tests for groin pain among four experienced clinicians. These included: strength testing of hip adduction, strength testing of the psoas muscle, strength testing of abdominals (rectus abdominis and obliques), palpation of the adductor longus at the pubic bone, palpation of the pubic symphysis, palpation of the rectus abdominis at the pubic bone, palpation of the psoas muscle, passive adductor stretching, and iliopsoas muscle length testing. The percentage of intra-observer agreement was over 90 for all tests except the resisted psoas muscle test (85%). Likewise, the resisted psoas muscle test was the only test that

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Figure 1. Abdominal Anatomical Diagram (Used with permission of Mark Combs, Aurora, CO).
showed poor reproducibility and low inter-observer agreement. No determination was made in the study by Hölmich et al regarding the number of tests necessary to indicate a positive diagnosis of a sports hernia. In 2000, Meyers et al published a study reporting the physical findings of 157 patients (140 male, 17 female) prior to pelvic floor repair. Palpation results proved to be somewhat variable, with 35% of this sample demonstrating pain with palpation of the proximal adductor longus tendon and insertion, 9% with pain of the pubic symphysis, and only 7% with palpable tenderness of the lower abdominal and inguinal regions. Of significance in Meyer's study were the findings in which resisted adduction produced pain in 88% of this population, while resisted sit-ups produced pain in only 46% of this group.

Previously, diagnostic imaging was reported to be inconclusive in the identification of the sports hernia. Several authors noted magnetic resonance imaging (MRI) to be effective for ruling out underlying and associated pathology, but that it offered no significant findings in patients with the diagnosis of a sports hernia. More recent authors suggest improved imaging techniques utilizing a large field-of-view magnetic resonance (MR) survey of the pelvis, in combination with high-resolution MR of the pubic region to be an effective tool for evaluating athletes with the potential diagnosis of sports hernia. These protocols are noted to have improved accuracy in identification of adductor tendon and abdominal injury. It is suggested that greater understanding of musculoskeletal anatomy of the pubic region offered by these MR image findings, and specific patterns of pathology associated with athletic pubalgia may aide in the identification of the sports hernia.

With the lack of objective findings demonstrated using diagnostic methods such as radiographs, ultrasound, and computerized tomography (CT), the definitive diagnosis of a sports hernia has proven difficult without surgical exploration. Diagnosis most often is achieved following the exclusion of other potential pathology. After other potential sources of groin pain have been eliminated, focus can turn to the classic symptoms described by athletes with sports hernia. These symptoms can include a subjective complaint of groin and/or abdominal pain, pain which increases with activity and subsides with rest, tenderness over the pubic ramus/lateral border of the rectus abdominis/conjoined tendon, pain with resisted hip adduction, and pain with resisted abdominal curl-up. Unfortunately these symptoms exist with numerous other pathologies and the most accurate diagnostic method is surgical exploration and identification.

Treatment options have typically included conservative methods such as modalities, physical therapy, and anti-inflammatory medication, followed by surgical repair when non-operative treatment fails. While numerous authors have reported exceptional success rates following surgical repair of the “sports hernia”, little has been published regarding conservative treatment of this pathology. Several authors report surgical treatment of patients who did not respond to conservative measures, however those reports fail to specify the non-surgical measures incorporated prior to the surgical procedure, vaguely referring to them as rest and physical therapy. While several authors suggest noninvasive treatment as an initial alternative to surgery, others state this to be ineffective.

In a recent case report, six collegiate athletes were diagnosed with a sports hernia using five classic signs and symptoms which the authors referred to as the “cluster of five”. These include: complaints of deep groin/lower abdominal pain, exacerbation of pain with sports activity which is relieved by rest, tenderness with palpation of the pubic ramus, pain with resisted hip adduction, and pain with resisted sit-up test. Of these athletes, three of the individuals were treated non-surgically and three surgically. While postoperative results were favorable for the surgical cases, the non-surgical patients did not have a long-term follow-up to adequately evaluate the effectiveness of the conservative treatment option used.

To the knowledge of the authors, no literature has been published describing the long-term follow up of the athlete with a non-surgically treated sports hernia. The purpose of this case report is to describe the non-surgical management of a professional athlete with the characteristic signs and symptoms of a sports hernia.
CASE DESCRIPTION

At the time of injury, the subject was a 26-year-old ice hockey player who had played in the NHL for 4 years. No history of groin or abdominal injury was noted prior to this incident. The injury occurred during the second period of an NHL contest. The player was turning to his left with weight on both skates when he was pushed abruptly in the back by an opponent (Figure 2). During contact, the player’s trunk was forced into extension followed by right hip abduction and extension as his weight was transferred to his left skate (Figure 3). Following the forcible contact from the opponent, the subject’s trunk and upper body moved into flexion as he struggled to recover and maintain his balance. The player reported experiencing an immediate sharp pain in the lower abdomen and right groin region during contact. He was unable to complete the rest of the game because of the acute pain and disability associated with the injury.

Upon evaluation the following day, the athlete reported significant right lower abdominal and groin discomfort with all activity including ADLs such as basic trunk mobility of rolling in bed, sit to stand, and walking. The athlete was observed ambulating in a protected, flexed-trunk posture with difficulty moving from sitting to supine. No effusion or ecchymosis was noted over the lower abdominal or right thigh region. Physical examination revealed trunk AROM limited by pain; right hip AROM limited approximately 25% by sharp abdominal/groin pain in all planes of motion; hip strength 3-/5 limited in flexion and adduction by pain; 4/5 right hip flexion strength when passively placed in 90 degrees of flexion; pain with attempted abdominal curl-up test; and pain with palpation of the right lateral rectus abdominis border as it inserted on the pelvis, as well as pain in the inguinal ligament region and right adductor longus tendon. The physician found no palpable defect or hernia. An MRI was performed with no significant abdominal or adductor findings, as well as an absence of pubic symphysis pathology. Following the patient history, physical examination and MRI results, sources of injury such as back/pelvis and hip joint dysfunction, neural entrapment, and internal disorders were ruled out. A diagnosis was then made of sports hernia.

The decision was made to treat the subject’s injury with a conservative approach due to the physical findings, insignificant MRI results, and the experience of the physician and medical staff. For the purpose of this case report, the rehabilitation program can be described in three basic phases: Phase 1 - pain management/initiation of flexibility and stabilization, Phase 2 - strength and stability progression, Phase 3 - functional progression.
and return to sport. No time frame was assigned to each phase of rehabilitation, rather, the player's subjective responses and objective clinical findings were used to guide advancement between phases.

**Phase 1: Pain Management and Initiation of Stabilization Physical Evaluation:**

Upon evaluation two days post injury, this patient's findings are summarized in Table 1:

Pain level was rated with a verbal analog scale from 0 to 10, where 0 represents an absence of pain, and 10 represents the worst pain imaginable. The patients' resting pain level was rated 3/10, and 8/10 with activity such as hip flexion and trunk flexion. Pain was also noted with basic bed mobility and coughing. Palpation revealed tenderness over the right lateral aspect of the pubic symphysis/rectus abdominis insertion, anterior aspect of the superior pubic rami as well as the adductor longus origin and tendon.

Trunk AROM was found to be within normal limits for all motions except extension, during which discomfort was noted over the lower abdominal region. Active range of motion of the right hip was limited secondary to pain in all planes. Passive range of motion for the involved hip joint was unremarkable with the exception of abduction and extension. Abduction was limited approximately 10% secondary to adductor discomfort proximally, while extension was limited approximately 10% secondary to discomfort over the anterior aspect of the hip and lower abdominal region.

Muscle strength was reduced in abdominal and hip muscle groups, both primarily due to discomfort. The abdominals were assessed following Kendall's testing procedure for rectus abdominis, external obliques and internal obliques. Abdominal testing was graded 3+/5 for rectus abdominis and external/internal obliques. The ability to activate the transversus abdominis (TrA) was evaluated by manual palpation just inferior and medial to the pelvic ASIS landmark where it is most superficial, using the abdominal drawing-in maneuver in the supine position. Additional evaluation was performed with use of a pressure biofeedback cuff for this same contraction, and control of lumbar neutral position. When palpating TrA during attempted contraction, the purpose was to feel for tightening without protrusion of the obliques or rectus abdominis. Use of the pressure biofeedback involved placing the pressure cell under the lumbar spine just superior to the buttocks with the patient lying in a supine position with both knees bent. The pressure cell was then inflated to 20 mmHg as indicated by the pressure gauge, and the patient instructed to perform an abdominal drawing-in exercise with pelvic floor contraction moving the pelvis from an anterior tilt into a neutral pelvic position. As the abdominal drawing-in exercise was performed the pressure gauge reading should increase with a goal of 40 mmHg which was monitored by the patient visually. The ability to attain a neutral pelvic position and then maintain the needle position on 40 mmHg was necessary before adding peripheral exercises with upper and lower extremities. The athlete was unable to actively contract the transversus abdominis when assessed with palpation, and unable to control a neutral trunk position when assessed with pressure biofeedback while attempting the abdominal drawing-in maneuver supine.

Hip strength was tested following the manual muscle testing procedures outlined by Kendall with the exception of adduction. Adduction was tested following the guidelines established by Dos Winkle, in which testing is performed at 0, 45 and 90 degrees of hip flexion. In addition hip adduction was tested at 0 degrees of hip flexion with the patient holding both legs just off the table unsupported. The author has found this test to be most difficult and painful in individuals with symptoms of sports hernia. The subject's right hip was graded 3-/5 for hip flexion, extension, internal and external rotation, adduction in neutral with elevation, and 3/5 for adduction in all other positions. Hip abduction was graded 4-/5.

Special Tests: Segmental lumbar and pelvic passive accessory motion testing was evaluated and assessed. Manual evaluation of segmental motion has been shown to be reliable with experienced clinicians. While the interrater reliability with manual evaluation has proven to be poor, Gonnella et al reported good intrarater reliability with testing of joint mobility. Lumbar segmental mobility was found to be normal, however pelvic alignment and mobility were dysfunctional upon evaluation. Position testing of pelvic landmarks demonstrated a posterior rotated position of the right ilium on the left sacrum. Mobility testing demonstrated hypomobility of the right sacroiliac joint (SIJ).
Passive accessory mobility testing of the hip was normal and equal bilaterally.  

Functional level was assessed with emphasis on ambulation and activities of daily living. The subject reported minimal discomfort with normal cadence walking; however did have abdominal and proximal deep adductor discomfort with ascent of stairs. This required climbing with single step progression and the assistance of the hand rail. In addition, considerable discomfort and difficulty were noted with sitting to supine and supine to sitting maneuvers such as getting in and out of bed.

**Phase 1 Interventions:**
The subject received manual therapy intervention and exercise rehabilitation 5 days a week. The first phase of treatment focused on pain management as well as early initiation of stabilization and exercise. Cryotherapy and interferential electrical stimulation were implemented due to their anti-inflammatory and analgesic effects. Manual therapy focused on soft tissue mobilization to address muscular tightness and length of hip musculature including flexors (iliopsoas, rectus femoris, tensor fascia latae), adductors (pectineus, adductor longus, adductor brevis and adductor magnus), and gluteals (gluteus maximus, gluteus medius and gluteus minimus). Soft tissue techniques were performed in a pain-free range of motion to avoid tissue trauma. Pelvic mechanics and mobility were treated using a left side lying technique with manual contacts of the therapist producing and anterior rotation of the right innominate. This technique was performed using Grade III and IV mobilizations as well as grade V manipulation. Mobilization was performed with 5 sets of 20 repetitions. Treatment was discontinued when position and mobility were re-tested and assessed to be within normal limits (WNL) as compared to the opposite side.

Due to lower abdominal discomfort, the subject was unable to perform land based strengthening and stabilization training. Because of these limitations hydrotherapy was introduced with a pool exercise program taking advantage of the benefits of buoyancy on the reduction of weight bearing and tissue stresses, as well as the potential abdominal support provided due to hydrostatic compression of the water. Aquatic exercise included walking, hip strengthening with straight leg swings against water resistance as tolerated by pain, bilateral squats, and modified trunk stability while performing the abdominal drawing in maneuver. As the patient was able to control the pelvis and trunk with the drawing-in stability exercise in the pool, knee lifts (within pain-free abilities only) were added to the exercise program. Once the subject was able to tolerate and control basic exercises in the weight reduced environment of the water, a land-based stabilization program was initiated to address deficits in trunk, hip and pelvic stability. Phase 1 of rehabilitation lasted four days.

Criteria for advancement to Phase 2 of rehabilitation included resting verbal analog pain scale rating of “0”, pain-free ADLs including ambulation and ascent of stairs, and the ability to tolerate land based supine trunk stabilization training.

**Phase 2: Stability and Strength Progression**

**Physical Evaluation:**
Following Phase 1 of the athlete’s rehabilitation, the findings were as follows:

Pain level was rated at rest 0/10 or no pain, and 3/10 during moderate intensity activities including pool jogging, land based trunk stabilization, and biking. No pain was noted with palpation of the right adductors, and minimal pain with palpation over the right lower abdominal region. Discomfort was noted over the right lower abdominal region with the resisted abdominal crunch test (single repetition). The resisted abdominal crunch was performed to test not only rectus abdominis strength, but also the attachment along the pubis for pain with resistance.

Trunk AROM was WNL for all motions except extension in which mild discomfort/tightness was noted over the lower abdominal region at end range. Active range of motion of the involved hip was WNL in all planes with the exception of right hip extension that was limited by approximately 25%. Passive range of motion for the involved hip joint was WNL in all planes.

Right hip strength was improved in all planes of motion to 4+/5, with the exception of adduction, which tested 4/5 with mild discomfort. The rectus abdominis improved to 4-/5 while external obliques and internal obliques were 4/5 with manual muscle
testing scores. Manual palpation testing demonstrated that the athlete was able to initiate an active contraction of TrA and control a neutral trunk position supine during pressure biofeedback evaluation following guidelines outlined earlier.

Special testing found pelvic position and SIJ mobility to be WNL.

Functional level was improved and the patient was able to accomplish pain free ambulation, ascent and descent of stairs as well as full bed mobility with minimal discomfort. Pool exercise of moderate intensity as described in phase one interventions was tolerated well.

**Phase 2 Interventions:**
The second phase of rehabilitation began when the subject was able to tolerate supine transversus abdominis training with pressure biofeedback without pain. The subject continued to receive manual therapy interventions and exercise rehabilitation progression 5 days a week by the same physical therapist. The player was evaluated daily for trunk and hip ROM and strength, as well as with palpation of hip and abdominal musculature for tightness and pain. Following evaluation, manual therapy intervention consisted of soft tissue mobilization to address muscular pain and tightness described in phase 1. All soft tissue mobilization was performed in a minimal to pain-free manner to avoid further trauma. Modalities including IFC and cryotherapy continued, with the goal of reducing the risk of inflammation post treatment.

Exercises in this phase were initially based on a modified “dying bug” progression, with abdominal drawing-in and pelvic floor co-contraction to facilitate TrA recruitment. Activation of the TrA was initiated with the subject in the supine position due to the comfort of this position, ease of monitoring TrA activity by the therapist, and the ability of the therapist to instruct the subject in volitional control of TrA function in this position. Stabilization continued with progression to quadruped, kneeling, and half-kneeling positions, and eventually to standing activities which promoted additional muscular recruitment from multifidus, psoas, gluteals, and obliques. Exercises incorporated reciprocal upper and lower extremity motion with resistance bands, and activity progression stressing all planes of motion while controlling stability of the trunk and pelvis. Initially focus was directed on intrinsic trunk stabilization with the ability to contract TrA properly and maintain lumbar neutral in supine (Figure 4). As TrA control improved, peripheral demands were added, progressing to the ability to control the neutral pelvic position in supine with unsupported bilateral upper and lower extremities (Figure 5). Once this was achieved weight bearing exercise emphasizing lumbar neutral control with upper and lower extremity resisted motion was introduced in all planes including forward and lateral lunge walking, and rotational patterns (Figures 6–10). Difficulty was increased as the patient mastered each specific task with regard to hip, pelvis, and trunk components.

Hip strengthening with an emphasis on gluteus medius and maximus muscle groups was incorporated into phase 2 treatment. This included bilateral and unilateral bridging, side-lying abduction leg lifts, and standing resisted hip abduction and extension.

![Figure 4. Supine Pelvic Neutral Position.](image)

![Figure 5. Supine Position with Reciprocal Upper and Lower Extremity Motion.](image)
Weight room strengthening exercises were also initiated in this phase and performed under the direction of the primary author beginning with bilateral machine activities such as leg press, hamstring curls, and quadriceps extensions. This was progressed to unilateral performance of each, and then to weight bearing activities such as wall squats and weighted lunges in all planes of motion. Lunges were performed with a gradual increase in step length to increase difficulty. Resistance training utilized a 10 repetition maximum (RM) per set routine to stress muscular fatigue and build lower extremity strength during this phase. These activities were monitored closely for discomfort and correct performance, with verbal and tactile cuing for emphasis of lower abdominal/pelvic floor control.

Aquatic therapy continued with advancement of intensity including forward jogging, backward running, and lateral shuffles, with progression to sprints emphasizing hip motion and cadence. The pool used was 25 meters long and 5 feet deep. Running shoes were worn for foot protection. As higher intensity running was tolerated, the subject was timed during the pool runs. Goals were set prior to each aquatic treatment for repetitions at maximal effort, racing against previous best times. Verbal cuing was used to stress TrA contraction while maintaining trunk/pelvic neutral control during increasing efforts of exercise. In addition, kick board swimming was initiated and advanced with timed laps to emphasize hip strength and speed.

Balance and proprioceptive exercises were initiated and emphasized during this phase of rehabilitation beginning with single and multi-plane wobble boards, progressing to unilateral lower extremity balance activities similar to the star excursion test. Balance reach exercises involved unilateral lower extremity weight bearing while dynamically reaching in various planes of motion for distance with the upper and lower extremities. This exercise was used
not only for training, but evaluation as well. Initial measures while balancing on the right lower extremity demonstrated a significant asymmetry with upper and lower extremity reach as compared to balancing on the left lower extremity. This deficit was approximately 25%. Recent research has suggested a correlation between core stability and star excursion test results.69

Criteria for advancement to phase 3 included a verbal analog pain rating of minimal (1 on a scale of 0 to 10 as described previously) with moderate effort exercise, 5/5 MMT values for abdominals and hips, pain-free progression of standing stability exercises (Figures 3–7) with resisted bands in forward and lateral directions, pain-free pool sprinting 25 meter length x 40 seconds, star excursion lower extremity reach distance 80% involved versus noninvolved, and unilateral leg press 1 repetition maximum (RM) 90% involved versus noninvolved leg.70 The second phase of rehabilitation lasted 14 days.

Phase 3: Functional Progression and Return to Sport Physical Evaluation:
Following Phase 2 of this athlete’s rehabilitation, the findings were as follows:

Pain level was rated at rest 0/10 or no pain, and 1/10 during moderate/high intensity activities including pool running, trunk stabilization, and biking. No pain was noted over the adductors or right lower abdominal region with abdominal crunches.

AROM of the trunk was within normal limits for all motions including extension, and WNL for the right hip in all planes.

Manually tested hip strength was 5/5 for all hip muscle groups including the adductors. The rectus abdominis, external obliques and internal obliques all tested 5/5 as well. Pressure biofeedback evaluation found the subject was able to contract and control the trunk using the TrA in supine, holding the pelvis in neutral while performing upper extremity flexion with reciprocal
lower extremity extension with a resistance band (Figures 4 and 5). Palpation evaluation of lower abdominal tone continued in weight bearing positions to provide feedback to the subject for the desired abdominal contraction. The therapist utilized tactile assessment to aid in evaluation of abdominal performance during activities in weight bearing (Figures 6–10). Although this manual palpation is a subjective judgment, the author has found it to be useful for assessing abdominal activity during upright moving activities.

Functional level was improved with pain free ascent and descent of stairs as well as full bed mobility without discomfort. Balance reach measurements improved to WNL by the end of phase 2. Pool exercise including, jogging/running/sprints and hip strengthening were all well tolerated.

**Phase 3 Interventions:**

This phase began when tolerance to all advanced stability exercises was achieved without pain in erect postures. Exercise progression was focused on trunk/pelvis and hip stability with increasing intensity. This initially was stressed with pool exercise emphasizing speed and stride length in straight planes, progressing to diagonal movements and pivoting.

Resisted bungee cord ambulation was also initiated and progressed in forward, backward, and lateral directions. As intensity was increased with no subjective reports of pain, the difficulty of tasks was progressed to include grapevine and pivoting motions, and later stick-handling (with a tennis ball instead of a puck) with and without obstacles, and speed bursts.

Additionally, lateral slide board training was used beginning with a short stride length (approximately 50% of normal stride) at 30 second timed intervals. The stride length was gradually widened requiring increased strength of pushing leg and stability of glide leg/trunk/pelvis. Interval times were initially increased to 60 seconds to facilitate endurance training, followed by more rapid push-off cadence requirements simulating higher intensity skating demands. Verbal cuing of TrA contraction continued as previously described. Stick handling and passing drills using a tennis ball were incorporated into the slide board activities to simulate core stability demands of skating while performing peripheral activities such as sport specific ice hockey skills. Once these activities were tolerated, on ice functional progression was initiated.

On ice rehabilitation began with unidirectional lap skating of approximately 25% effort for a time period of 20 minutes. Each subsequent day addressed advancing of ice time, increasing subject effort, and adding skills. The subject was progressed to 30 minutes on ice the next day, and skills were advanced to include forward cross-overs in both directions and stick-handling with a puck. By the third day, the effort level was increased to 50% of maximum. By the end of the first week, ice time was increased to 60 minutes and included skills additions of backward skating, pivoting forward to back and reverse and low effort wrist shots. Skating intensity was elevated gradually to approximately 70 percent maximum effort. In the second week of on ice rehabilitation, the primary goal was to increase effort toward 90 percent of maximum. On ice skills began to incorporate passing drills and increased shooting intensity including backhand, snapshots, and slap shots. In addition, the subject began to perform drills with his teammates that were
predominantly offensive in nature involving passing and shooting. Once the subject reached 90 percent effort without recurrence of symptoms limiting his performance, the final four days of his on ice work was focused on return to full practice demands including contact and battling drills. The final evaluation of return to play was based on the subject’s ability to participate in full on ice activities simulating game situations and intensity, including full acceleration, stops and start drills, one on one battling and full contact checking drills. His on ice practice time was approximately 120 minutes per day. It should be noted that the subject experienced several significant episodes of abdominal/groin discomfort during this phase of his rehabilitation, and daily evaluation was needed prior to on ice workouts for proper progression of sport specific tasks. This on ice progression lasted 17 days. The subject continued a maintenance stability warm-up program prior to on ice participation for the rest of the 2001-2002 NHL season. The entire duration of the third phase was 31 days. Please note that the summary of all findings and interventions by stage can be found in the Appendix.

OUTCOMES
The subject was treated for 49 days from injury until return to full competition. At the completion of phase 3, the subjective pain level was reported to be 0 to 1/10 with full on-ice participation. No pain was noted with coughing, and palpation of the rectus abdominis insertion or inguinal/adductor structures was pain-free as well. Both active and passive trunk and hip ROM were WNL and comparable bilaterally, as well as manual muscle test grades for all hip and abdominal muscle groups being 5/5. In addition, the subject displayed full functional ability with return to non-restricted on ice participation and game competition. The individual in this case study has continued to play professional ice hockey for the same NHL team for the past eight seasons without recurrence of these symptoms.

The subject of this case report was informed, and agreed to the intention of the authors to submit the data of this injury and rehabilitation for possible publication.

DISCUSSION
In a study of NHL players completed from 1991 to 1997, 617 “groin/abdominal” injuries were reported. Over this six-year period however, a significant increase in this diagnosis was noted from 12.99 injuries/100 players/year in 1991/92 to 19.87 injuries/players/year in 1996/97.71 While the incidence of this condition appears to have increased, a potential explanation of this rise may be attributed to more accurate identification by physicians and trainers. Various explanations for the cause of a sports hernia have included anatomical deficiencies as well as repetitive and excessive stresses creating a lengthening and/or tearing of these structures,14,17,18 While many authors note frequent occurrence of the sports hernia with repetitive stress, this case report represents an example of a specific incident of excessive force resulting in injury. The individual in this case report had no previous history of groin or abdominal pain prior to the acute episode.

Studies addressing surgical repair of the “sports hernia” have noted involvement of the rectus abdominis,19,23 internal oblique,26 external oblique,9,27,29 transversus abdominis,72 as well as transversalis fascia and conjoint tendon14,18,40,73 as structures of dysfunction indicating the broad range of abdominal involvement. Another consideration is the close proximity of attachment of rectus abdominis and adductor longus tendons to each other and the pubic symphysis, creating a potential shearing effect across the anterior aspect of the pelvis as the hips move in all planes with the lower extremity in a closed chain position. This then creates potential for stretching and tearing of tissues such as the transversalis or conjoint tendon, weakening the region structurally and resulting in groin and lower abdominal symptoms.

Treatment options for the patient diagnosed with a sports hernia have traditionally involved conservative care, followed by surgical repair for those individuals who do not achieve satisfactory recovery or are unable to return to their desired activity.17,18,21,22,24,40,42 While numerous reports have been written regarding repair and recovery of those who have sustained sports hernias, few have addressed the non-surgical care of these patients. Several authors have cited poor results with conservative treatment,15,21,26,39 but have failed to define the specific detail or extent of non-operative treatment other than vague reference to rest, modalities, and therapy. While understandable considering the purposes of their studies, this information is important in order to develop a better
understanding of non-operative methods of treatment that have the greatest potential for success.

The treatment methods utilized in this case report emphasized lumbopelvic stabilization with progression of peripheral extremity and postural demands, with incorporation of this core control into functional progression and return to sport. This progression of stabilization has been incorporated by the authors into the rehabilitation of multiple athletes with the diagnosis of sports hernia. While specific exercises and tasks in the rehabilitation program may vary depending on the anatomic details of the injury and the athlete’s response to treatment, the rehabilitation principles of the development of neuromuscular control and sequencing of the core musculature are consistent. Many options and various adaptations for exercise selection exist, however the authors have found the specific exercise selection to be far less significant than the application of the underlying principles. The primary emphasis of this rehabilitation program was on neuromuscular control and sequencing, as well as static and dynamic postural stability.

Richardson et al, found active contraction of the TrA by individuals performing an abdominal drawing-in exercise affected stability of the pelvis by increasing stiffness of the sacroiliac joints. Further study has shown the functional role of the TrA in postural control and stability during unilateral weight bearing, including increased symmetrical TrA activity in normal healthy individuals during unilateral activity. Multiple studies by Hodges et al have demonstrated that TrA activation in healthy individuals occurs prior to other muscular firing related to upper and lower limb movement. In contrast, significant delays in firing of the TrA have been shown to be present in individuals with low back pain. Further research on subjects with low back pain confirmed a delayed TrA activation when tested with electromyography (EMG) prior to voluntary TrA exercise activation. Following a single treatment the same subjects displayed improvement in TrA response time approaching that of normal individuals.

Anatomically, the TrA is the deepest layer of abdominal muscle, wrapping around the abdomen between the lower ribs and pelvis. The transversalis fascia, which lies deep to the transversus abdominis, is part of the endoabdominal fascia that encases the abdominal cavity and forms the posterior wall of the inguinal canal. It is reinforced by aponeurotic fibers from the transversus abdominis, although these have been described to occur in varying quantities. In an anatomical dissection, Condon describes the complex anatomy of the transversus abdominis and transversalis fascia and their relationship in the protection of this region. Together they comprise the transversalis fascial sling. Contraction of the TrA functionally pulls the transversalis fascia sling together, laterally, and superiorly forming a “shutter” mechanism. The movement of the transversalis fascia acts to draw the internal inguinal ring under the muscular wall of the internal oblique, functionally closing this space. In addition a “sphincteric” mechanism occurs causing constriction of the internal inguinal ring at the same time. This mechanism protects the area during activity and strenuous events from increasing intra-abdominal pressure which could lead to a hernia.

Although the transversus abdominis doesn’t completely cover the lower abdominal region and has limited aponeurotic fiber attachments to the transversalis fascia that forms the posterior inguinal restraint, the basis for this exercise protocol may be partially explained by a means similar to the “shutter” mechanism described by Condon. With the anatomical attachment of the transversus abdominis to the transversalis fascia, exercise targeting the deep abdominals produces a “corset” type action to support and stabilize the abdominal wall. This contraction causes the transversalis fascia to become taut and to generate a “bracing” effect throughout the lower abdomen to aid in stability of the lower trunk, pelvis and hips.

Limitations of this case report include the difficulty of arriving at the diagnosis of sports hernia, as this syndrome most likely represents many related but potentially distinct pathologies. Diagnosis is also difficult in that there is no definitive physical examination or radiological test that objectively defines this pathology. As a result, diagnostic testing relies heavily on the exclusion of other pathology.

In actuality, the only definitive diagnosis of a sports hernia is likely through surgical exploration and successful recovery following surgical treatment. In addition, while the subject of this case report had a successful recovery and returned to his pre-injury level of competition, the underlying reasons for this
success are difficult to define. As a professional athlete his pre-injury level of fitness, his compliance with the treatment program, and motivation to return to his sport are large contributors to his success. The treatment program in this case report requires a high level of effort and attention to detail. Without this motivation, effort and dedication, the chances of recovery are diminished significantly. Another limitation is the fact this case report represents a single individual. A larger number of subjects would help to distinguish the effectiveness of such conservative measures in the treatment of sports hernia. In the authors’ experience, the conservative treatment outlined in this case report has proven successful in a number of the patients with sports hernia diagnoses that have been encountered. However, there are subjects who do not respond to this treatment protocol, and have subsequently undergone surgical repair. Future research to define the various pathologies that are responsible for this diagnosis, the diagnostic tests that yield objective evidence of the pathologies, and those findings that would direct patient assignment to either conservative or operative protocols would be helpful.

In review of the literature, no case studies were found specifically addressing conservative treatment of a sports hernia with return to full activity. While this patient responded exceptionally well to conservative methods, the authors do not believe this is an exclusive treatment option. An appropriate, successful rehabilitation program is modified depending on the anatomic contributions to the injury and the patient’s response to each phase of the program. In the instance where a conservative program fails, operative intervention may resolve the patient’s symptoms. In the authors experience conservative treatment has been very effective, however there are examples of individuals who may not respond to this treatment, or do not have the dedication necessary for success.

REFERENCES
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APPENDIX

<table>
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<tr>
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<td>Functional Progression and Return to Sport</td>
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<td>WNL all planes</td>
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ABSTRACT

Physical therapists treating adolescent and young adult athletes with low back pain complaints should have a high level of clinical suspicion of the possibility for spondylolysis, spondylolisthesis, or developing stress reactions of the pars interarticularis. This case outlines the use of conventional radiography, computerized tomography, and Single photon emission computed tomography (SPECT) in the differential diagnosis for an adolescent cricket athlete with low back pain.

Key words: diagnostic imaging, differential diagnosis, low back pain

DIAGNOSTICS CORNER
LOW BACK PAIN IN A COMPETITIVE CRICKET ATHLETE

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INTRODUCTION
Competitive athletes presenting with low back pain provide multiple decision making challenges for physiotherapists. Criteria are not well defined to direct management regarding initiating care immediately or perhaps delaying treatment until diagnostic imaging is completed. Whether to pursue a course of care focused on mobilization or stabilization is often a key element of the dilemma. This case report highlights the difficulty in initial patient management decisions in athletes presenting with low back pain.

CLINICAL PRESENTATION
A male, age 17, reported for physical therapy consultation for his primary complaint of low back pain upon referral by his primary care physician. His description of symptoms was of dull and intermittent pain with the peak being at 6 of 10 on a visual analog scale. He denied any distal symptoms, including paresthesia.

He reported a history of pain of five days duration with the onset during a college cricket match. He was bowling early in the match in the fifth over when he noticed the onset of the pain. (Figure 1) (Figure 2) An over is a set of six consecutive balls bowled in succession toward a batsman with the side fielding usually bowling 50 overs in total during a match at this level of cricket. He continued to bowl for three additional overs until the pain increased to the level requiring him to withdraw from that session. He awoke the next morning with complaints of stiffness in his low back and attempted to continue participating, although in a different position on the field. Because of worsening left low back pain and he was unable to bowl or train. He subsequently consulted with a physician within one week of this exacerbation and reported to physical therapy one week after seeing the physician.

Notable in this patient’s recent history was an increase in the intensity and method of his training program during a college holiday period. He had also been attempting a new bowling technique with more “front on action” or positioning the coronal plane of the trunk directed toward the batsman.

His past history was remarkable for an anterior cruciate ligament rupture and reconstruction two years prior with successful rehabilitation. Recovery from this injury was sufficient to allow his return to competitive
100 and 200 meter sprinting. He denied any other significant health issues.

At this time of his presentation for physical therapy, he reported symptoms in the left low back as being at a level of one of 10 on a numerical pain scale with activities of daily living. The 24-hour behavior of his symptoms included complaints of stiffness before bed, with minimal disturbance of sleep because of pain. A brief interval of subjective stiffness was reported upon waking in the morning, but this was reduced within 20 minutes of rising. His symptoms throughout the day were reported as minimal, but increased with prolonged standing to 2 of 10 on a verbal analog scale.

Once provoked, the patient described his symptoms as remaining irritated for approximately 30 minutes. He reported being able to lessen his back pain with recumbent positioning and taking an over-the-counter analgesic.

**EVALUATION**

At the time of initial consultation with the physical therapist, the patient presented with normal gait and no obvious antalgic patterns of spontaneous movement. Upon visual observation and palpation, his lumbar lordosis appeared to be increased along with the impression of greater than typical resting tone in the paraspinal musculature while standing. Lumbar flexion was not restricted and the patient displayed only mild pain occurring upon his return to an upright, neutral position. Standing extension was also within normal expectations, but with end of range discomfort. Standing extension also revealed segmental hinging, or the appearance of excessive movement at one level and a reduction of movement at adjacent levels, which was observed by the examining clinician. Lateral flexion movement elicited complaints of feeling “stiff” with pain being reported with left lateral flexion. The one-legged hyperextension test provoked left-sided low back pain when performed on the left side. Passive accessory motions of the lumbar vertebrae provoked pain on the left at L4-5, but with no detectable movement loss. Palpation also revealed generalized tenderness of the left low back and increased firmness of the left paraspinal musculature. Sacroiliac pain provocation tests were negative. Hip range of motion was within normal limits and hip quadrant testing was negative. Hamstring muscle length was asymmetrical with less length present on the left. Trigger points were located in the left gluteal and proximal hamstring musculature. The patient reported that radiographs of his lumbar spine were recently completed at the direction of his primary care physician and these were reported to be negative for fractures. (Figures 3a and 3b).

Because of suspicion of pars interarticularis injury, the patient was referred back to his primary care physician for additional diagnostic evaluation. The absence of identifiable hypomobility accounting for his back pain, pain provocation with lumbar extension, and his age placing him in a high risk population for spondylolysis or spondylolisthesis raised the suspicion for pars interarticularis injury during examination and subsequent evaluation by the evaluating physiotherapist.

**DIAGNOSTIC IMAGING IN PATIENTS WITH SUSPECTED PARS INTERARTICULARIS LESIONS**

Although the patient in this case presented with conventional radiographs of his lumbar spine interpreted as negative (Figures 3a and 3b), unremarkable radiographic results must be considered with caution in individuals with suspected pars interarticularis lesions. The absence of an overt spondylolisthesis on radiography

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**Figure 3. Standard radiographs of the lumbar spine of this athlete, a) lateral view, b) lateral oblique view.**
does not rule out more subtle forms of pars interarticularis pathology. As the pars interarticularis lies oblique to all three orthogonal planes, the standard radiological views often do not align with the desired anatomy ideally and, thus, a bony lesion may be missed.  

The defect of spondylolysis in radiography is visualized as a lucent zone in the region of the pars interarticularis, which is classically described as having the appearance of a collar on the "scotty dog" or a broken neck as seen in lateral oblique radiographs. Standard three-view radiography has been reported to be insensitive to 20% of spondylolysis with only the lateral oblique view offering diagnostic value. Other investigators have suggested a collimated lateral view to be slightly more sensitive. Particularly problematic in the diagnostic process is the common occurrence of asymptomatic pars lesions. Spondylolysis and spondylolisthesis have been found to occur equally as often in those individuals without symptoms as those with complaints of low back pain. Thus, low back symptoms in some persons can be inaccurately attributed to the pars lesions, but can be unrelated to the cause(s) of low back pain. Beyond basic radiography multiple additional imaging modalities may contribute to diagnosis of pars interarticularis lesions.

Magnetic resonance imaging (MRI) has also been used in the diagnostic challenge of decision making of those with suspected spondylosis or spondylolysis. MRI can also demonstrate an on-going process with fluid sensitive and fat-suppressed imaging sequences such as T2-weighted and short tau inversion recovery (STIR) with reverse angle oblique images. Greater signal intensity, consistent with edema, may be demonstrated in the pars interarticularis with these sequences. Additionally, T1-weighted images also offer the best anatomical detail, also with reverse angle oblique images. Incomplete fractures, however, may not be revealed with MRI because of its inability to depict cortical bone integrity. The reverse oblique angles may be necessary as standard slices in the cardinal planes may allow lesions to escape detection. Three-dimensional MRI imaging, if available, may offer greater sensitivity than standard MRI. In the presence of radicular signs or symptoms, MRI is clearly indicated for visualization of the soft tissue, including the neural elements. Another benefit of MRI is the absence of ionizing radiation, which may be a particularly relevant consideration for younger individuals.

Computed tomography (CT) is very sensitive in detecting a compromise in the integrity of cortical bone with its multiplanar reconstructions and is generally considered to be most accurate in identifying a fracture. On CT scan, spondylolysis and spondylolisthesis are well demonstrated as a linear lucidity or defect extending through the pars interarticularis. CT, however, may not reveal a stress reaction in which there is no overt disruption of the cortical bone. As CT technology has advanced, including volume rendering, the ability to detect smaller anatomical defects has commensurately improved. However, CT delivers relatively high levels of ionizing radiation.

Increased metabolic activity, typical of a stress response, can be revealed by nuclear imaging. Scintigraphy, with increased radioisotope uptake in the region of the pars interarticularis, suggests a metabolically active lesion and, thus, is diagnostically important when correlated with symptoms. Studies directly comparing radiography and scintigraphy suggest that scintigraphy is more sensitive in identifying posterior element pathology. The weakness of scintigraphy in suspected pars lesions, as with most of its musculoskeletal applications in first line imaging, is its relatively limited specificity in differential diagnosis. The increased uptake of radio-isotope is often attributable to multiple potential origins or causes.

Single photon emission computed tomography (SPECT) is considered most accurate in identifying an on-going process with greater anatomical specificity when related to current symptoms. Similarly, the on-going activity offers information as to the potential for healing of the lesion. If the increased metabolic activity from the lesion has ceased, there is likely to be no increase of radioisotope uptake. As a result, chronic lesions may not be detected. Thus, SPECT alone may not be an appropriate first order diagnostic procedure.

Perhaps most valuable is the combination of CT and SPECT. Tomography of a scintigram enables localization of the increased radioisotope signal to the
posterior vertebral elements, specifically the pars interarticularis. The presence of a normal CT accompanied by significant findings with SPECT suggests no overt fracture, but a stress response present at the pars interarticularis. Such results may point to the potential for a large treatment effect in which the fracture may be prevented with activity management and rehabilitation. The cricket athlete in this case represents this subgroup of patients. Current American College of Radiology Appropriateness Criteria recommends for suspected spondylolysis or stress fracture in athletes, bone scintigraphy with SPECT followed by limited CT, if the SPECT is positive.

In Figures 4a and 4b, axial and sagittal CT reconstructions demonstrate no identifiable pathology. Figure 5, however, reveals increased uptake of the radioisotope at the posterior elements of L4-5. Thus, the CT images indicate no frank fracture being present, but the SPECT study reveals increased metabolic activity, consistent with a stress response.

**PHYSICAL THERAPY MANAGEMENT PROCESS**

Once the pars stress reaction was identified, relative rest, including cessation of his sporting activity, was initiated. He was specifically restricted from participating in cricket and bowling for six weeks. He also immediately began a course of physiotherapy focusing on activation and training of the spinal stabilizing musculature, including the transversus abdominis and lumbosacral multifidi. The design of this exercise program was directed at neutral positioning of the lumbar spine with low load, high repetition activities in a Pilates-like program. He was also directed to avoid large excursions of trunk movement, particularly in extension. This exercise program was enhanced by real-time feedback with rehabilitative ultrasound while in the clinical setting and a pressure biofeedback unit for use at home. Once optimally recruited, training of the target musculature for endurance was the objective.

After successfully participating in this phase for approximately two weeks, he demonstrated full, pain-free lumbar motion while lying. His trunk motor control exercise progression was advanced to more challenging positions, including quadruped. Additionally, lower extremity muscle extensibility specific to his sporting demands were addressed, such as ankle dorsiflexion and hip musculature length in all planes. Unilateral declined squats with a focus on neutral spine positioning were also initiated. The arabesque exercise was introduced to train control of the spine with flexion over the forwardly placed lower extremity, similar to the demands of bowling.

At four weeks, more dynamic and loading exercise was introduced, including hopping on various surfaces with the focus on controlled, unilateral landing. Gentle rotatory movements of the trunk were incorporated into his exercise program and motion mimicking bowling activity against light elastic band resistance was also introduced. Re-education regard-
ing his bowling style toward more side-on and semi-side-on positions also began. These alignments of the trunk are generally considered to lessen the risk of spinal injury compared to the front-on technique with which he had been experimenting prior to the worsening of his symptoms. The front-on style of bowling may result in greater lumbar compressive and rotational forces during the approach.

At approximately six weeks, he was allowed to bat into the cricket nets, thereby challenging dynamic rotation, as well as begin gentle jogging. Monitoring of his progress continued to include the requirement that each progressive step be achieved without inducing low back symptoms. He soon after began practicing bowling into the nets with activity specific reconditioning.

OUTCOME
At approximately eight weeks following diagnosis and the initiation of his individually designed exercise program, he returned to competition. He was able to participate fully without return of symptoms. Follow-up at six months revealed that he has remained symptom free.

RECOMMENDATIONS FOR THE FUTURE
The challenge for physiotherapists is discriminating those persons who present with simple mechanical low back pain fully within the scope of practice from those who present with a more complex condition, perhaps caused by a disturbance of the structural integrity of the lumbar spine. Adolescent and young adult athletes are particularly at risk for injuries to the pars interarticularis. In a study of over 4200 athletes with low back pain, 590 (13.9%) had radiologically identifiable spondylolysis and among those with identifiable pars lesions 47.5% (280) had spondylolisthesis.20 Among the athletic populations most at risk are cricket players.21-23 The action of bowling requires movement of the trunk in all three cardinal planes with compressive forces through the lumbar spine exceeding eight times that of body weight.22,23 Examination features alerting the clinician to potential pars defects have not been well defined. The one-legged

Figure 5. SPECT Images; note darker areas, indicative of increased uptake of the radioisotope at the posterior elements of L4-5.
standing hyperextension test used in the examination of this patient, although positive, has not withstood scrutiny when studied. This test has been shown to have 55.2% sensitivity, 67.6% specificity, a negative predictive value of 46.9%, and a positive predictive value of 53.8% for detecting active spondylolysis in young, active patients with low back pain. Thus, the one-legged hyperextension test should not be relied upon for diagnosis or exclusion of pars interarticularis lesions. Other authors have reported palpable lesions to correlate well with radiological results. These palpable findings, however, assume a relatively large magnitude of displacement with spondylolisthesis and perhaps do not represent the majority of patients in whom the physiotherapist would be attempting to utilize such decision making. Other authors have offered anecdotal reports of a shortened stride, flexed hips and knees in stance and during gait, and either flattened or increased lumbar lordosis.

Physiotherapists treating adolescent and young adult athletes with low back pain complaints should have a high level of clinical suspicion of the possibility for spondylolysis, spondylolisthesis, or developing stress reactions of the pars interarticularis. No single algorithm to guide decision making for proceeding with conservative care or referring for diagnostic imaging has been validated. In the predominance of patients presenting with low back pain, diagnostic imaging results do not influence care choices. Among the population represented by this athlete, however, clinician knowledge of imaging selection and interpretations based on patient specific clinical reasoning contributed directly to treatment choices.

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ABSTRACT

Stretching is a common activity used by athletes, older adults, rehabilitation patients, and anyone participating in a fitness program. While the benefits of stretching are known, controversy remains about the best type of stretching for a particular goal or outcome. The purpose of this clinical commentary is to discuss the current concepts of muscle stretching interventions and summarize the evidence related to stretching as used in both exercise and rehabilitation.

Key words: Exercise, fitness, rehabilitation, stretching

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INTRODUCTION

Human movement is dependent on the amount of range of motion (ROM) available in synovial joints. In general, ROM may be limited by 2 anatomical entities: joints and muscles. Joint restraints include joint geometry and congruency as well as the capsuloligamentous structures that surround the joint. Muscle provides both passive and active tension: passive muscle tension is dependent on structural properties of the muscle and surrounding fascia, while dynamic muscle contraction provides active tension (Figure 1). Structurally, muscle has viscoelastic properties that provide passive tension. Active tension results from the neuroreflexive properties of muscle, specifically peripheral motor neuron innervation (alpha motor neuron) and reflexive activation (gamma motor neuron).

Obviously, there are many factors and reasons for reduced joint ROM only one of which is muscular tightness. Muscle “tightness” results from an increase in tension from active or passive mechanisms. Passively, muscles can become shortened through postural adaptation or scarring; actively, muscles can become shorter due to spasm or contraction. Regardless of the cause, tightness limits range of motion and may create a muscle imbalance.

Clinicians must choose the appropriate intervention or technique to improve muscle tension based on the cause of the tightness. Stretching generally focuses on increasing the length of a musculotendinous unit, in essence increasing the distance between a muscle’s origin and insertion. In terms of stretching, muscle tension is usually inversely related to length: decreased muscular tension is related to increased muscle length, while increased muscular tension is related to decreased muscle length. Inevitably, stretching of muscle applies tension to other structures such as the joint capsule and fascia, which are made up of different tissue than muscle with different biomechanical properties.

Three muscle stretching techniques are frequently described in the literature: Static, Dynamic, and Pre-contraction stretches (Figure 2). The traditional and most common type is static stretching, where a specific position is held with the muscle on tension to a point of a stretching sensation and repeated. This can be performed passively by a partner, or actively by the subject (Figure 3).

There are 2 types of dynamic stretching: active and ballistic stretching. Active stretching generally involves moving a limb through its full range of motion to the end ranges and repeating several times. Ballistic stretching includes rapid, alternating movements or ‘bouncing’ at end-range of motion; however, because of increased risk for injury, ballistic stretching is no longer recommended.1 Pre-contraction stretching involves a contraction of the muscle being stretched or its antagonist before

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Figure 1. Factors contributing to muscle tension.
stretching. The most common type of pre-contraction stretching is proprioceptive neuromuscular facilitation (PNF) stretching. There are several different types of PNF stretching (Table 1) including “contract-relax” (C-R), “hold-relax” (H-R), and “contract-relax agonist contract” (CRAC); these are generally performed by having the patient or client contract the muscle being used during the technique at 75 to 100% of maximal contraction, holding for 10 seconds, and then relaxing. Resistance can be provided by a partner or with an elastic band or strap (Figure 4).

Other types of pre-contraction stretching include “post-isometric relaxation” (PIR). This type of technique uses a much smaller amount of muscle contraction (25%) followed by a stretch. Post-facilitation stretch (PFS) is a technique developed by Dr. Vladimir Janda that involves a maximal contraction of the

<table>
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<th>Table 1. Types of PNF stretching</th>
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<tr>
<td>Contract Relax (CR)</td>
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<td>Contract-Relax Agonist Contract (CRAC)</td>
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The effectiveness of stretching is usually reported as an increase in joint ROM (usually passive ROM); for example, knee or hip ROM is used to determine changes in hamstring length. Static stretching often results in increases in joint ROM. Interestingly, the increase in ROM may not be caused by increased length (decreased tension) of the muscle; rather, the subject may simply have an increased tolerance to stretching. Increases in muscle length are measured by “extensibility”, usually where a standardized load is placed on the limb and joint motion is measured. Increased tolerance to stretch is quantified by measuring the joint range of motion with a non-standardized load. This is an important question to consider when interpreting the results of studies: was the improvement based on actual muscle lengthening (ie, increased extensibility) or just an increase in tolerance to stretch? Chan and colleagues showed that 8 weeks of static stretching increased muscle extensibility; however, most static stretching training studies show an increase in ROM due to an increase in stretch tolerance (ability to withstand more stretching force), not extensibility (increased muscle length).

Static stretching is effective at increasing ROM. The greatest change in ROM with a static stretch occurs between 15 and 30 seconds; most authors suggest that 10 to 30 seconds is sufficient for increasing flexibility. In addition, no increase in muscle elongation occurs after 2 to 4 repetitions.

Unfortunately, however, static stretching as part of a warm-up immediately prior to exercise has been shown detrimental to dynamometer-measured muscle strength and performance in running and jumping. The loss of strength resulting from acute static stretching has been termed, “stretch-induced strength loss.” The specific causes for this type of stretch induced loss in strength is not clear; some suggest neural factors, while others suggest mechanical factors. Furthermore, the strength loss may be related to the length of the muscle at the time of testing or the duration of the stretch. Interestingly, a maximal contraction of the muscle being stretched before static stretching may decrease stretch-induced strength loss.
Contraction of a muscle performed immediately before it is stretched is effective at increasing ROM. While most pre-contraction stretching is associated with PNF-type contract-relax or hold-relax techniques using 75 to 100% of a maximal contraction, Feland et al. showed that submaximal contractions of 20 or 60% are just as effective, thus supporting the effectiveness of post-isometric relaxation stretching. Interestingly, ROM increases are seen bilaterally with pre-contraction stretching, supporting a possible neurologic phenomenon. The specific phenomenon associated with an increase in flexibility following a pre-stretch contraction remains unclear. Many have assumed that muscle experiences a refractory period after contraction known as ‘autogenic inhibition’, where muscle relaxes due to neuro-reflexive mechanisms, thus increasing muscle length. Interestingly, electromyographic (EMG) studies have shown that muscle activation remains the same or increases after contraction. Some researchers have speculated that the associated increases in ROM are related to increased stretch tolerance rather than a neurological phenomenon. Some researchers suggest that Hoffman reflexes (H-reflexes) are depressed with a pre-contraction stretch. The H-reflex is an EMG measurement of the level of excitability of a muscle: lower H-reflexes are associated with lower excitability. It is possible that the lowered excitability levels may allow muscle to relax through the gamma motor neuron system despite an increased activation through the alpha system. Obviously, more research is needed to investigate these neurological effects of pre-contraction stretching.

### COMPARING STRETCHING MODES

Several authors have compared static and dynamic stretching on ROM, strength, and performance (See Table 2). Both static and dynamic stretching appear equally effective at improving ROM acutely or over time with training. Several authors have found no improvement in performance when comparing static and dynamic stretching. In contrast to static stretching, dynamic stretching is not associated with strength or performance deficits, and actually has been shown to improve dynamometer-measured power as well as jumping and running performance.

### Table 2. Stretching Techniques Comparative Matrix, based on studies comparing at least 2 techniques.

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*No significant difference between static and dynamic stretching (nc = no change; † = improved; ‡ = diminished)

**No significant difference between pre-contraction stretch and static stretching**
The literature is conflicting regarding the effects of warm-up stretching prior to exercise. Static and dynamic warm-ups are equally effective at increasing ROM prior to exercise.56,57 Some researchers report static stretching after warm-up decreases performance,32,33,35 while others report no change or an increase in performance.32,38,64,65 While static stretching is generally followed by an immediate decrease in strength, static stretching performed before66 or after warm-up57 does not decrease strength. The volume of static stretching may also affect performance: Robbins et al37 reported that 4 repetitions of 15-second holds of static stretching did not affect vertical jump, while 6 repetitions reduced performance.

A pre-stretch contraction has been associated with greater acute gains in ROM compared to static stretching in many studies;48,50,67-73 however, several studies show similar increases in ROM45,76-84 and performance77,81,82,84 when comparing pre-contraction stretching and static stretching. Both acute static stretching and pre-contraction stretching have been shown to decrease strength.26,83

RECOMMENDATIONS
Static, dynamic, and pre-contraction stretching are all effective methods of increasing flexibility and muscle extensibility; however, these modes may be more effective in specific populations. Several authors have noted an individualized response to stretching;48,56,60 therefore, stretching programs may need to be individualized.

Well-rounded Exercise Programs
For a general fitness program, the American College of Sports Medicine1 recommends static stretching for most individuals that is preceded by an active warm-up, at least 2 to 3 days per week. Each stretch should be held 15-30 seconds and repeated 2 to 4 times.

Many exercise studies on older adults include stretching exercises as part of a well-rounded exercise program. Unfortunately, there is no clear dose-response for flexibility training in older adults because stretching interventions are often combined with strengthening, balance, and cardiovascular activities, making it difficult to isolate stretching's effectiveness. Older adults may need longer stretch times than the recommended 15 to 30 seconds; Feland et al85 found that 60-second holds of static stretches were associated with greater improvements in hamstring flexibility in older adults compared to shorter duration holds. Ten weeks of static stretching of the trunk muscles was able to increase spinal mobility (combined flexion and extension ROM) in older adults.86 Static stretching of the hip flexors and extensors may also improve gait in older adults.87 Furthermore, the effectiveness of type of stretching seems to be related to age and sex: men and older adults under 65 years respond better to contract-relax stretching, while women and older adults over 65 benefit more from static stretching.

Warm-up for Sports and Exercise
Stretching performed as part of a warm-up prior to exercise is thought to reduce passive stiffness and increase range of movement during exercise. In general, it appears that static stretching is most beneficial for athletes requiring flexibility for their sports (e.g. gymnastics, dance, etc.). Dynamic stretching may be better suited for athletes requiring running or jumping performance30 during their sport such as basketball players or sprinters.

Stretching has not been shown to be effective at reducing the incidence of overall injuries.88 While there is some evidence of stretching reducing musculotendinous injuries,88 more evidence is needed to determine if stretching programs alone can reduce muscular injuries.3

Rehabilitation
Stretching is a common intervention performed during rehabilitation. Stretching is prescribed to increase muscle length and ROM, or to align collagen fibers during healing muscle.

Several researchers have investigated different muscle stretching techniques on subjects with tight hamstrings. Some authors report that both static and pre-contraction stretching are able increase acute hamstring flexibility,47,54,89 while others suggest static stretching90,92 or PNF stretching10,71 are more effective. It appears that 6 to 8 weeks of static stretching is sufficient to increase hamstring length.14,93,94

Stretching is effective for the treatment of orthopedic conditions or injury; however, as with other populations, outcomes may be based on the individual
patient. Static stretching has been shown to be more effective than dynamic stretching for those recovering from hamstring strains. In addition, it has been reported that athletes with hamstring strains recover faster by performing more intensive stretching than by performing less intensive stretching. Patients with knee osteoarthritis can benefit from static stretching to increase knee ROM, however, PNF stretching may be more effective. Chow et al reported that total knee replacement patients benefited from 2 weeks of either static, dynamic or PNF stretching to increase ROM.

Stretching is often included in physical therapy interventions for management of shoulder, back and knee pain. Despite positive outcomes of these types of studies and improvements in flexibility, it is difficult to isolate the effectiveness of the stretching component of the total treatment plan because the protocols usually include strengthening and other interventions in addition to stretching.

A recent review of stretching for contractures found no improvement in joint mobility orthopedic-related contractures. Orthopedic contractures often result from shortness in non-contractile tissues such as capsuloligamentous structures rather than muscle tightness.

Researchers have shown that 12 months of stretching is as effective as strengthening exercises or manual therapy in patients with chronic neck pain. In addition, patients with chronic musculoskeletal pain demonstrate an increased tolerance to stretch after 3 weeks of static stretching. Lewit and Simons reported an immediate 94% reduction in pain associated with trigger points after applying a PIR technique. These studies support stretching in pain management programs.

Stretching appears to have no benefit for neurological patients who have had a stroke or spinal cord injury. Because of a strong neurological component and long-standing muscle shortening associated with these conditions, it’s no surprise that simple muscle stretching techniques are not effective.

**SUMMARY**

The benefits of stretching seem to be individual to the population studied. Several factors must be considered when making clinical recommendations from the literature. To increase ROM, all types of stretching are effective, although PNF-type stretching may be more effective for immediate gains. To avoid decrease in strength and performance that may occur in athletes due to static stretching before competition or activity, dynamic stretching is recommended for warm-up. Older adults over 65 years old should incorporate static stretching into an exercise regimen. A variety of orthopedic patients can benefit from both static and pre-contraction stretching, although patients with joint contractures do not appear to benefit from stretching.

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ABSTRACT
The new graduate, or the licensed physical therapist with general orthopedic experience, is not qualified to provide sideline coverage at athletic events. Additional or advanced training in emergency care is essential to provide aid in acute situations. Completion of the First Responder certification prepares an individual to react appropriately to any emergency on the sidelines, in the clinic, or in the community. The highest qualification that a physical therapist can attain to ensure adequate preparation for the practice of Sports Physical therapy is the ABPTS Sports Certified Specialist (SCS) designation. This professional designation indicates that this individual is highly qualified to care for athletes at any level, from on the sidelines, through rehabilitation and return to play, regardless of the injury, age of the athlete, or skill level.

Key words: Emergency care, sideline coverage, sports physical therapist

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INTRODUCTION
From a historical standpoint, in nearly 40 years of clinical practice with 36 of those years caring for injured athletes, I have had the opportunity to educate hundreds of physical therapy students in the clinical setting. The overwhelming majority of these students come to our clinical sites due to our involvement with high school sports and the opportunity to provide event or sideline coverage. Many of these students have had previous involvement with high school sports as a player, but seldom do we get a student with experience in acute injury or illness management. The exceptions to this example are students who have previous experience as an athletic trainer, Emergency Medical Technician, or registered nurse with Emergency Room experience.

In conversation with these students, I am continually amazed at the lack of basic emergency skills and knowledge in physical therapy students and their ability to react appropriately in emergency situations. These students have an excellent understanding of anatomy, physiology, pathology, pathomechanics, and the basic knowledge necessary to acquire the skills needed to provide pre-hospital care for injured or ill athletes. These students are certainly not lacking in interest or the willingness to learn and are willing to devote the extra hours necessary to prepare to provide these services in future situations requiring emergency care. These students as well as our clinical/Sports Physical Therapy staff recognize the need for continued education in the area of pre-hospital care of injured athletes if we, as a profession, are to continue to pursue this specialty area of Sports Physical Therapy. The problem extends beyond the physical therapy student and involves those physical therapists who are providing pre-hospital care without sufficient education in the management of emergency situations. The decision as to whether or not to provide these services in future situations requiring emergency care.

WHO OWNS THE PROBLEM?
The problem lies with the physical therapist licensed to practice in their respective state who feels as though basic, entry-level physical therapy education is sufficient to qualify them to provide sideline coverage. These physical therapists place themselves in a very dangerous and precarious situation. The risk lies with the athlete however; as every physical therapist is not adequately prepared to provide sideline coverage or offer pre-hospital care based solely on their physical therapy education.1,2

Granted, there are many situations in which the physical therapist is required to evaluate an injured athlete with the outcome of the evaluation being the decision as to whether or not to return the athlete to training, participation, or competition. Many physical therapists are quite capable of evaluating musculoskeletal related injuries in terms of the “return to play” aspect of care which occurs in the clinic. This decision making capability comes with basic education, knowledge of the mechanism of injury, the ability to evaluate the injury, knowledge of the sport and the physical demands of the sport as well as the environment to which the athlete is returning. Should the decision of the physical therapist not take into account all of these aspects, the return to play decision may be inaccurate and place the athlete at risk for further injury or re-injury.

In contrast, inaccurate decisions regarding return to play in sideline or acute situations have no place in the realm of Sports PT because they could be catastrophic. A choice made on the field or about returning an athlete to the field of play could be a life or death decision.3,4 For example, the case of the athlete with a concussion, an improper decision to return the athlete to play could result in catastrophic injury or death. An athlete who is rendered unconscious as a result of trauma awakens with no apparent neurological deficit may have an unstable cervical spine as a result of the blow to the head. (Figure 1) The decision to return this player to competition or practice without a comprehensive, accurate examination could have catastrophic results if the player receives another blow to the head or spine. An athlete who receives a blow to the abdomen resulting in splinting of the abdominal musculature and pain in the left shoulder may have suffered an injury to the...
spleen which could be catastrophic if not managed properly. Many other emergency situations exist on the sidelines that require additional formal education and experience beyond the basic education of a physical therapist. Although inaccurate decisions have been made in the past by persons involved with pre-hospital care of the injured athlete, we, as Sports PT's, have an obligation to our profession, our athletes, fans, coaches, and officials to minimize these errors in sports health care.

EMERGENCY PREPAREDNESS: THE EMERGENCY RESPONDER CERTIFICATION

One method of increasing the preparation for pre-hospital care of the athlete in emergent situations is through attendance at the Sports Physical Therapy Section's Emergency Medical Response course. This is an American Red Cross course designed specifically for the physical therapist with an interest in Sports Physical Therapy and is one of the requirements for those who wish to sit for the American Board of Physical Therapy Specialties' (ABPTS) certification examination. Upon completion, the participant receives a two (2) year certification from the American Red Cross as a First Responder. The course will help prepare you, as a Sports PT, to provide sideline care at athletic events and provide necessary emergency care until more advanced medical care arrives in the form of Paramedics, and/or Emergency Medical Technicians. The course not only covers emergency care for traumatic injuries, but also CPR, use of the AED, airway insertion, management of many varieties of acute illnesses, and other topics related to pre-hospital care that are necessary to provide appropriate care on the sidelines of athletic events. Another pathway to becoming a competent provider of emergency and pre-hospital care is participation in a Sports Physical Therapy Residency. Each Sports Physical Therapy Residency program requires the completion of the Emergency Medical Response course prior to beginning the residency program if the resident is not an Emergency Medical Technician or Athletic Trainer. The outcome of these residency programs is certification as an ABPTS Sports Certified Specialist. The Sports PT must realize that in some cases, they are the “most medical” person present at an event or competition. Therefore, injuries incurred during the competition or event will often require the assistance and guidance from the Sports PT. Occasionally, an individual suffering from an onset of sudden illness may seek their care. The Sports PT must therefore be equipped to manage both traumatic neuromusculoskeletal injuries as well as sudden illness experienced by players, coaches, officials, cheerleaders, and fans. The process of caring for these individuals is a constant “decision making process” that involves immediate care, contacting the local emergency medical service, packaging and transportation of severely injured athletes and individuals, as well as return to play decisions. As mentioned previously, these decisions are not to be taken lightly as, on occasion, the decision may be life saving.

The role of the appropriately prepared Sports PT goes beyond the realm of athletics. We, as Sports PT’s, simply cannot ignore the needs of our communities and their residents. Should we possess the ability, skills, and knowledge to appropriately manage emergencies within our community, we should apply those skills to assist those in need. We cannot simply stop being a Sports PT at the end of the day or at the end of the game. We must be vigilant in our respective environments and provide assistance to those in need of emergency care whether it is in the athletic arena, in work environments, or in the community in which we live.

In conclusion, the new graduate, or the licensed physical therapist with general orthopedic experience, is not qualified to provide sideline coverage at athletic events. Additional or advanced training in emergency care is
essential to provide aid in acute situations. Completion of the First Responder certification prepares an individual to react appropriately to any emergency on the sidelines, in the clinic, or in the community. The highest qualification that a physical therapist can attain to ensure adequate preparation for the practice of Sports Physical therapy is the ABPTS Sports Certified Specialist (SCS) designation. This professional designation indicates that this individual is highly qualified to care for athletes at any level, from on the sidelines, pre-hospital care through rehabilitation and return to play as quickly and as safely as possible regardless of the injury, age of the athlete, or skill level.

REFERENCES