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<th>Page Number</th>
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<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>149</td>
<td>An Initial Evaluation of BTrackS™ Balance Plate and Sports Balance Software for Concussion Diagnosis</td>
<td>Goble DJ, Manyak KA, Abdennour TE, Rauh MJ, Bawja HA</td>
</tr>
<tr>
<td>164</td>
<td>Effectiveness of Ultrasonography in Diagnosing Chronic Lateral Ankle Instability: A Systematic Review</td>
<td>Radwan A, Bakowski J, Dew S, Greenwald B, Hyde E, Webber N</td>
</tr>
<tr>
<td>190</td>
<td>Comparison of Trunk and Lower Extremity Muscle Activity Among Four Stationary Equipment Devices: Upright Bike, Recumbent Bike, Treadmill, and ElliptiGO®</td>
<td>Bouillon L, Baker R, Gibson C, Kearney A, Busnemeyer T</td>
</tr>
<tr>
<td>201</td>
<td>Not All Single Leg Squats Are Equal: A Biomechanical Comparison of Three Variations</td>
<td>Khuu A, Foch E, Lewis CL</td>
</tr>
<tr>
<td>220</td>
<td>Lower Extremity Hypermobility, But Not Core Muscle Endurance Influences Balance in Female Collegiate Dancers</td>
<td>Ambegaonkar JP, Cortes N, Caswell SV, Ambegaonkar GP, Wyon M</td>
</tr>
<tr>
<td>230</td>
<td>Acute Changes in Passive Glenohumeral Rotation Following Tennis Play Exposure in Elite Female Players</td>
<td>Moore-Read SD, Kibler WB, Myers NL, Smith BJ</td>
</tr>
<tr>
<td>237</td>
<td>Static Stretching Does Not Reduce Variability, Jump and Speed Performance</td>
<td>de Oliveira FCL, Rama LMP</td>
</tr>
<tr>
<td>254</td>
<td>Acute Effects of Dry Needling on Posterior Shoulder Tightness: A Case Report</td>
<td>Passigli S, Pidharsi G, Poser A</td>
</tr>
<tr>
<td>302</td>
<td>Return to Play Progression for Rugby Following Injury to the Lower Extremity: A Clinical Commentary and Review of the Literature</td>
<td>Sclafani MP, Davis CC</td>
</tr>
</tbody>
</table>
ABSTRACT

**Background:** As recently dictated by the American Medical Society, balance testing is an important component in the clinical evaluation of concussion. Despite this, previous research on the efficacy of balance testing for concussion diagnosis suggests low sensitivity (~30%), based primarily on the popular Balance Error Scoring System (BESS). The Balance Tracking System (BTrackS, Balance Tracking Systems Inc., San Diego, CA, USA) consists of a force plate (BTrackS Balance Plate) and software (BTrackS Sport Balance) which can quickly (<2 min) perform concussion balance testing with gold standard accuracy.

**Purpose:** The present study aimed to determine the sensitivity of the BTrackS Balance Plate and Sports Balance software for concussion diagnosis.

**Study Design:** Cross-Sectional Study

**Methods:** Preseason baseline balance testing of 519 healthy Division I college athletes playing sports with a relatively high risk for concussions was performed with the BTrackS Balance Test. Testing was administered by certified athletic training staff using the BTrackS Balance Plate and Sport Balance software. Of the baselined athletes, 25 later experienced a concussion during the ensuing sport season. Post-injury balance testing was performed on these concussed athletes within 48 of injury and the sensitivity of the BTrackS Balance Plate and Sport Balance software was estimated based on the number of athletes showing a balance decline according to the criteria specified in the Sport Balance software. This criteria is based on the minimal detectable change statistic with a 90% confidence level (i.e. 90% specificity).

**Results:** Of 25 athletes who experienced concussions, 16 had balance declines relative to baseline testing results according to the BTrackS Sport Balance software criteria. This corresponds to an estimated concussion sensitivity of 64%, which is twice as great as that reported previously for the BESS.

**Conclusions:** The BTrackS Balance Plate and Sport Balance software has the greatest concussion sensitivity of any balance testing instrument reported to date.

**Level of Evidence:** Level 2 (Individual cross sectional diagnostic study)

**Keywords:** balance, BTrackS, concussion, diagnostic accuracy, sensitivity
INTRODUCTION
While sports participation offers many benefits to the athletes involved, widespread participation and awareness, has led to an increase in both the prevalence and reporting of sports-related concussions.1,2 Sports-related concussions are brain injuries caused by biomechanical forces transmitted to the head during participation in sporting activities.3 The ensuing brain damage is unpredictable and often results in a multitude of symptoms.4 Given this unpredictable presentation, sports medicine professionals rely on a battery of clinical assessments in order to determine the presence of a concussion. This includes measures of gross symptomology (e.g. blurred vision, nausea), cognitive function (e.g. working memory, attention) and motor ability.

With respect to motor ability, the most recent statement by the American Medical Society5 advised the use of balance testing in concussion protocols. This recommendation was based on numerous reports showing evidence of balance declines following concussion.6-9 Despite this, few reports exist quantifying the efficacy (i.e. specificity/sensitivity) of balance testing for sports-related concussion.10 In one of the only known studies on the topic, McCrea et al6 found that balance testing had poor concussion sensitivity (~30%), even though it had a high degree of specificity (~90%).

The limited concussion sensitivity of balance testing reported by McCrea et al6 may be due to the type of balance test administered. These authors report balance based on the Balance Error Scoring System (BESS), an observational tool that relies on tester judgement to count the number of balance errors made by an athlete during standing trials of varying difficulty.11 The BESS is well accepted in the field of sports medicine, with an estimated 84% usage among athletic trainers who include balance testing in their concussion protocols.12 Despite its popularity, however, the BESS has reliability issues due to its subjective nature.13-15 Indeed, it has been shown to require large changes in performance (~62% change from baseline) before a confident determination of a balance decline can be made based on the BESS.15 For these reasons, the BESS may not be well-suited for picking up the subtle changes in balance associated with concussions of mild to moderate severity.

A more sophisticated approach to concussion balance testing is the objective measurement of body sway control via a force plate device. Force plate technology is the “gold standard” for balance testing, abstracting the center of pressure (COP) from foot contact forces generated during standing on the plate. COP is a proxy for body sway control and increased center of pressure displacement is a known indicator of balance decline in individuals with traumatic brain injuries, including concussion.8,16-17 Unfortunately, force plate balance testing is only used by 5% of athletic trainers who perform balance testing as part of their concussion protocols.12 This under-utilization is most likely due to the high cost (~$5000-$75,000), and general lack of portability, associated with typical force plate systems.

The Balance Tracking System (BTrackS, Balance Tracking Systems Inc., San Diego, CA, USA) consists of a force plate (BTrackS Balance Plate) and software (BTrackS Sport Balance) which can quickly (<2 min) perform concussion balance testing with gold standard accuracy. This instrument is relatively low cost (~$800) compared to other force plates, and extremely portable for multisite use. The present study sought to evaluate the sensitivity of the BTrackS Balance Plate and Sport Balance software for identifying concussed athletes. It was hypothesized that the BTrackS Balance Plate and Sport Balance software would have increased concussion sensitivity compared to that reported previously for the popular BESS test, given the use of objective, accurate and reliable, force plate technology.

METHODS
Participants
A cross-sectional sample of 25 collegiate athletes (mean age = 20.7; 14 women, 11 men) was utilized for this study. Athletes were chosen from a larger sample of 519 collegiate athletes who underwent baseline balance testing with the BTrackS Balance Plate and Sport Balance software when healthy in preseason. Participants were those individuals who later experienced a concussion in the ensuing sport season. This was verified within 48 hours of injury by a trained sports medicine professional (i.e. team physician) using the third version of the Standard Concussion Assessment Tool.18 Participants were
also required to have performed follow-up balance testing using the BTrackS Balance Plate and Sport Balance software within 48 hours of their concussive event. The 48 hour timeframe utilized was based on previous studies showing that balance deficits resolve between 3 and 10 days following a concussive event. All procedures in this study were approved by the local Human Subjects Institutional Review Board and informed consent was obtained prior to data collection.

**Experimental Setup**

Experimental testing in this study was conducted using the BTrackS Balance Plate and Sport Balance software (Balance Tracking Systems Inc., San Diego, CA) (Figure 1). The BTrackS Balance Plate is an FDA registered, lightweight (<7 Kg) force plate specialized for determining the COP of foot forces placed on it during standing. The surface of the BTrackS Balance Plate measures 0.4 m by 0.6 m and uses four-sensor technology to determine COP with an accuracy and reliability that is comparable to other, more expensive force plate systems. The BTrackS Balance Plate used in this study was placed on a on a firm (concrete tile), level surface during testing, as per the manufacturer’s specifications. Leveling of the board was achieved via the adjustable legs on the BTrackS Balance Plate and verified with a bubble leveling tool.

The BTrackS Sport Balance software is an application-based program which was loaded onto an ASIS laptop (Model X200) with a Windows 8.1 operating system. The BTrackS Sport Balance software is a user-friendly interface that guides the tester through creating an athlete demographic-based profile, running a balance test and viewing relevant results. The BTrackS Balance Plate was connected to the laptop via a USB cable, which also provided power to the plate’s electronics (i.e. no AC power required). All balance testing was conducted by the local Athletic Training staff, who were experienced in the use of BTrackS technology.

**Balance Testing Protocol**

Balance testing was administered in preseason and post-concussion according to the BTrackS Balance Test (BBT) protocol. Each BBT took less than two minutes to administer and was performed with the athlete wearing socks. The BBT consists of four, 20s trials with minimal inter-trial delays (<10s), which began and ended with an auditory tone. The athlete stood as still as possible on the BTrackS Balance Plate with eyes closed, hands on hips and feet shoulder width apart during testing (Figure 2). The first trial was for familiarization purposes only, while...
the remaining three trials were used to calculate the BBT result. The BBT result was calculated by the Sport Balance software as the average COP excursion (i.e. COP path length) across trials. COP excursion is a proxy for total body sway control and, thus, larger BBT values indicated worse performance.8,16-17 An example of baseline and post-injury data from an individual with declined balance following concussion is provided in Figure 3.

**Determination of BTrackS Concussion Sensitivity**

The sensitivity of the BTrackS Balance Plate and Sport Balance software for concussion was quantified by calculating the percentage of concussed athletes who showed a decline in balance from baseline testing to post-concussion testing. The criterion for determining whether a decline in balance had occurred was an increase in the BBT result of more than 5 cm (i.e. more than 5 cm greater sway following concussion compared to baseline), as prescribed by the BTrackS Sport Balance software. This criterion value established by Balance Tracking Systems Inc19 and represents the minimum detectable change (MDC) for the BBT with a 90% confidence interval. Otherwise stated, 90% of healthy individuals tested show a BBT result that varies 5cm or less from one test to the next. This criteria is also equivalent to a testing specificity of 90%, which aligns well with that reported previously for the BESS.6

**RESULTS**

Baseline and post-concussion BBT results, as well as the difference from baseline to post-concussion (i.e. BBT change), is presented for all participants in Table 1. Based on the MDC criterion of the BTrackS Sport Balance Software, 16 of the 25 concussed athletes were identified as having a balance decline (i.e. had 6 cm or greater sway following concussion compared to baseline). This ratio corresponds to an estimated concussion sensitivity of 64.0%. Overall, in all participants the average change from baseline following concussion was more than three times (18.8 cm) as large as the MDC criterion, with a range of -5.0 cm to 94.0 cm. Of those individuals identified as having a balance decline, the average change in BBT result was 30.0 cm, which is six times greater than the criterion value.

**DISCUSSION**

The increasing number of sports-related concussions has become a public health issue and, thus, there is a distinct need to more accurately identify athletes who have sustained a concussion.1,2 Poor sensitivity (~30%) has been shown previously for the most popular balance testing protocol for concussions (i.e. the BESS).6 The present study provided an initial estimate of the concussion sensitivity of a new, low-cost force plate device called the BTrackS Balance Plate and its associated Sport Balance software. It was determined that the BTrackS Balance Plate and Sport Balance software is more than twice as sensitive (64%) as the BESS for concussion diagnosis. Given that the criterion value for establishing a balance deficit was at a level of specificity similar to that of the BESS (i.e. 90%), the present study's findings support adapting concussion protocols for...
the use of the BTrackS Balance Plate and Sport Balance software over less effective alternatives such as the BESS.

Greater sensitivity for the BTrackS Balance Plate and Sport Balance software likely stems from the use of force plate technology, widely considered to be the gold standard for balance assessment. Unlike the subjective BESS method, the BTrackS Balance Plate and Sport Balance software uses an objective measure of balance (i.e. COP) with a reliable balance testing protocol.20-21 The more accurate and reliable a clinical tool is, the smaller the amount of measured change needed to make a confident decision regarding a clinical outcome. Previous research on the BESS has estimated that a large average change in performance (~62%) is necessary to confidently determine the existence of a balance decline.15 The results of the present study suggest that the BTrackS Balance Plate and Sport Balance software can detect, on average, a much smaller balance change relative to baseline.

Only one other known study has assessed the sensitivity of a force plate system for concussion diagnosis.22 In that study, changes in body sway were measured in concussed athletes using the Sensory Organization Test (SOT). The SOT tracks an athlete’s COP with a force plate system similar to the BTrackS Balance Plate and Sport Balance software, but does so during six conditions designed to isolate various sources of sensory feedback (i.e. visual, proprioceptive, vestibular). The SOT efficacy results showed a similar concussion sensitivity (62%) to that reported in the present study for the BTrackS Balance Plate and Sport Balance software (64%). However, the criterion used to determine an SOT balance decline was reduced performance greater than one standard deviation from baseline on any of four outcome measures. When each outcome measure was considered in isolation, SOT sensitivity was greatly reduced (range 24%-36%). This is in addition to the practical limitations inherent to the force plate system needed to run the SOT, which has a cost of ~$75,000 and poor portability for multi-site use.

One limitation of the present study is that it focused on the diagnostic sensitivity of BTrackS Balance Plate and Sport Balance software within a 48-hour time period following concussion. Future studies are needed to determine whether the length of recov-

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Table 1. Summary of BBT results from baseline to post-concussion and evaluation of balance decline according to the BTrackS Sport Balance criterion of 5 cm minimal detectable change.
ery following concussion might also be tracked more accurately using this tool, since previous research suggests balance issues resolve within 3-10 days.\textsuperscript{1,4,16-17}

As well, it may be possible that use of a different COP outcome measure, could further increase the efficacy of the BTrackS Balance Plate and Sport Balance software. One outcome measure of particular interest to explore in future work would be approximate entropy of COP during quiet standing. This non-linear COP metric has previously been shown to have an increased effect size post-concussion compared to more standard spatial measures of COP size and displacement, including the path length measure used in the BTrackS Sport Balance Software.\textsuperscript{23}

In order to maximize applicability to the field, only the prescribed BBT protocol and MDC metric included with the BTrackS Sport Balance software was evaluated in this study. While it is beyond the scope of the present work, future studies are warranted which are aimed at further improving the sensitivity of concussion assessment with the BTrackS Balance Plate and Sport Balance Software. This may include exploration of such factors as the standardization of foot position, utilization of a different MDC threshold, or the application of compliant (foam) surfaces on top of the BTrackS Balance Plate. In this way, the present findings may actually represent the most conservative sensitivity estimate for the BTrackS Balance Plate and Sport Balance software's potential as a concussion diagnostic.

While the present study provides highly valuable information regarding the efficacy of the BTrackS Balance Plate and Sport Balance software for concussion assessment, it should be noted that a direct comparison of this device and other balance testing tools was not made. That is, the athletes tested in this study were not concurrently assessed with either the BESS method or a more expensive force plate system. Such a comparison of balance testing tools may prove valuable in future studies, but was not feasible for this initial evaluation of the BTrackS Balance Plate and Sport Balance software due to logistical reasons. First, the BESS method was not being used as a standard component of the local university's concussion protocol due to a lack of trained personnel and confidence in results. Second, expensive force plate systems were not available for widespread baseline testing of athletes, which would have limited the available sample for this study.

It is possible that some of the athletes in this study were able to mask a balance decline by intentionally underperforming during their baseline test. This seems unlikely however, as the baseline BBT results were generally quite good compared to those individuals who did not show a balance decline following concussion. Interestingly, there appears to be partial relationship between the baseline balance score the magnitude of drop-off in performance following concussion. Three of the four individuals with the greatest drop-off in balance (≥50cm) had baseline scores that were in bottom five of all concussed athletes tested. This suggests that the BTrackS Balance Plate and Sport Balance software may also be useful as an early identification system for individuals at high risk of concussion.

**CONCLUSION**

The present results provide important clinical insight regarding the effectiveness of the BTrackS Balance Plate and Sport Balance software for determining the existence of sports related concussions. While the sensitivity is still subject to improvement, it is superior to more subjective methods, such as the BESS. In this case, future studies are planned to demonstrate the combined efficacy of the BTrackS Balance Plate and Sport Balance software with other standard concussion metrics (i.e. symptomology and cognitive function). This approach will ultimately provide clinicians the greatest chance of preventing potentially life-threatening conditions such as second impact syndrome, and/or limit the long term effects of repetitive brain injuries such as chronic traumatic encephalitis.

**REFERENCES**


ABSTRACT

Background: More than one million adolescent athletes participated in organized high school sanctioned football during the 2014-15 season. These athletes are at risk for sustaining concussion. Although cervical spine active range of motion (AROM) and deep neck flexor endurance may serve a preventative role in concussion, and widespread clinical use of measurements of these variables, reference values are not available for this population. Cost effective, clinically relevant methods for measuring neck endurance are also well established for adolescent athletes.

Purpose: The purpose of this study was to report reference values for deep cervical flexor endurance and cervical AROM in adolescent football players and examine whether differences in these measures exist in high school football players with and without a history of concussion.

Methods: Concussion history, cervical AROM, and deep neck flexor endurance were measured in 122 high school football players. Reference values were calculated for AROM and endurance measures; association were examined between various descriptive variables and concussion.

Results: No statistically significant differences were found between athletes with a history of concussion and those without. A modest inverse correlation was seen between body mass and AROM in the sagittal and transverse planes.

Conclusion: The results of this study indicate that the participants with larger body mass had less cervical AROM in some directions. While cervical AROM and endurance measurements may not be adequate to identify adolescents with a history of previous concussions among high school football players. However, if a concussion is sustained, these measures can offer a baseline to examine whether cervical AROM is affected as compared to healthy adolescents.

Level of Evidence: 2c

Key Words: Adolescents, craniocervical flexion, concussion, performance measures
INTRODUCTION

Almost eight million high school students participated in sports in the United States in 2014-15 with football having 1,083,617 participants. As participation in football increases, there is potential for an increased number of adolescents presenting with sport-related injuries including injuries to the head or the neck.

Cervical spine measures such as muscle endurance and AROM are important to optimize sport performance in football players, yet little is known about the relationship of these measures to head impact and possible correlations with incidence of injuries to the head or neck injuries. Additionally, despite their common use as clinical measures, there is a lack of reference values for cervical AROM and deep cervical flexor endurance in high school adolescents.

Concussion is one of the most common injuries that occurs in high school football. An athlete with a stronger neck with normal range of motion is suggested to be capable of generating greater absolute tensile forces and producing greater tensile stiffness than an athlete with a weaker or ROM limited neck. Previous researchers have suggested that greater neck strength and greater tensile forces may provide a protective mechanism to mitigate forces and potentially reduce the odds of sustaining concussion. Additionally, children may be at greater risk for concussion as compared to adults due weaker strength of the neck musculature and greater head mass to body mass ratio. Broglio et al reported that physical maturation and associated neck strength contribute to the greater peak head linear acceleration observed in high school football players compared to collegiate players.

Cost effective, clinically relevant methods for measuring neck endurance are not well established for adolescent athletes. Despite the large number of studies examining cervical strength, none specifically explored isometric endurance of the deep cervical flexors using the craniocervical flexion test (CCFT) with adolescent athletes. The deep cervical flexors (operationally defined herein as the longus capitus and longus colli) are imperative to cervical spine stability and function. The deep cervical flexors may be adversely impacted after concussion, similar to the effects that are seen after a whiplash injury, and these muscles may require objective assessment. Jull et al found that the deep cervical flexors were weaker in individuals with neck pain. Individuals with neck pain have also been found to have decreased craniocervical flexion AROM and poor activation of the deep cervical flexors.

Reference values for deep cervical flexor muscle endurance and cervical AROM in adolescents have not been reported to the authors’ knowledge. No published studies have reported the association between concussion history and clinical measures of the cervical spine. The purpose of this study was to describe performance of adolescent football players on deep cervical flexor endurance and cervical AROM. A second objective was to examine if there was a difference in deep cervical flexor endurance using the CCFT and cervical AROM measured using the CROM, between high school athletes with and without a history of concussion.

METHODS

Subjects

A sample of 122 high school football players participated in this study of which 98 participated in the CCFT testing. Participants were recruited from three suburban high schools in two different counties in Michigan, USA. Prior to recruitment, the study protocol was approved by the Institutional Review Board (IRB) of University of Michigan-Flint, and the school board of participating schools. Participants included football players between the ages of 13 to 18 years, who were participating on a high school football team at the time of the study. Participants were excluded if they were currently medically restricted from sport participation. All participants (and legal guardians if under age 18) provided written consent. Participants under 18 years old also provided written assent.

Procedures

On the testing day, participants were asked to complete a demographic questionnaire that included age, athletic participation, history of a healthcare provider’s diagnosis of concussion, and history of neck and upper extremity injury. After the completion of the demographic questionnaire, the weight
and height of each participant was measured. Then, each participant advanced to one of the testing stations, deep neck flexor endurance or cervical AROM, as described below. The testing was performed in a pseudorandom order based on the station's availability. The examiners were blinded to the athlete's concussion and injury history.

**Deep neck flexor endurance.** In this study, the first stage of the CCFT was conducted for this population due to the fact that the deep cervical flexors are a key component of the stability and normality of motion in this adolescent population. The CCFT is used to assess the activation and endurance of the deep cervical flexors. Stage 1 of the CCFT requires an individual to attempt to perform a sequence of five progressive stages of craniocervical range of motion using a feedback air filled pressure instrument (STABilizer™ Chattanooga Group Inc., Hixon, TN) in order to quantify the motion. As previously described by Jull and colleagues, the test is completed with the participant in a hook lying position, arms at the side, and the air filled pressure feedback instrument, the STABilizer™ (Chattanooga Group Inc., Hixon, TN) properly placed at the cervico-occipital junction. Participants were instructed to keep their tongue on the roof of their mouth with teeth slightly apart during the testing, then were instructed to nod their head and neck enough to move the dial but not enough to force his or her head back or lift head from the table. Each participant was allowed to practice this slow and controlled motion until they were able to perform the technique correctly; no participant required more than three attempts to be able to perform the technique correctly. The starting baseline pressure in the feedback instrument (STABilizer™) was 20 mmHg. Consistent with the testing protocol, participants were asked to complete the craniocervical flexion nodding movement at increasing intervals of 2 mmHg from the start position; resulting in possible targets at the levels of 22 mmHg, 24 mmHg, 26 mmHg, 28 mmHg, and 30 mmHg. The last interval that the participant could hold for three seconds with proper technique was recorded as the target level of performance. The CCFT test was repeated three times using the same procedure described above and the best performance (i.e. higher mmHg level) of the three tests was used in this analysis. The construct validity of the CCFT has been previously established for deep neck flexor muscle activity magnitude, as measured against deep neck flexor EMG activity via a nasopharyngeal catheter. The CCFT has previously demonstrated excellent inter-rater reliability (ICC = 0.91) and intra-rater reliability (ICC = 0.98).

**Cervical AROM.** Cervical AROM was tested with the participant in a seated position. The test was completed with the participant sitting in an upright posture with hands on his/her thighs. The cervical range of motion (CROM) device (Performance Attainment Associates, Roseville, MN) was attached to the participant's head. Audette et al found the CROM device to have high test-retest reliability with ICC values ranging from 0.89 to 0.98, a standard error of the mean (SEM) of 1.6 to 2.8 degrees, and a minimal detectable change (MDC90) of 3.6 to 6.5 degrees. This work from Audette et al agrees with two other CROM reliability studies, both of which examined intra-rater reliability of the CROM device. Participants were instructed to perform active motion for cervical flexion, cervical extension, cervical side bending to the left and right, and cervical rotation to the left and right. To minimize the order effect, the testing order was randomized. Athletes performed three trials of each movement with a 15 second rest between trials. Cervical endurance and AROM measures were completed by two investigators. Both investigators were Orthopedic Certified Specialists (OCS) and each had over 10 years of clinical experience. Prior to the study, they completed a standardized instruction training and inter-rater reliability testing (ICC 3,1 = 0.98).

**STATISTICAL METHODS**

Descriptive statistics were used to describe the participant demographic characteristics in Table 1. The normality of the demographic variables (age, height and body mass), and the six AROM measures was examined using the Kolomogrov-Smirnov test. A correlation analysis was conducted to examine the relationship between age, height and body mass to outcome variables. For non-normally distributed variables, Spearman Rank Correlation coefficient was utilized ($r_s$). To examine if there was a difference between athletes with and without concussion.
history provided, independent t-test was performed for normally distributed AROM variables, or Mann Whitney U test was performed for non-normally distributed AROM variables.

Additionally, in order to examine the association between concussion history and muscle endurance and AROM, participants were classified as either a “low performer” (below the median) or “high performer” (above the median) for each of six active range of motion movements and the performance of the CCFT. The dispersions across the high and low performers for all outcome measures was analyzed using 2 (high performer/ low performer) *2 (with concussion history/ without concussion history) Chi-square goodness of fit analysis. The odds of being classified as low performer against the reference odds of being a high performer across groups with and without concussion history were computed. An odds ratio less than 1 indicate that concussion is associated being classified as a low performer at the given measure. Odds ratio were considered significant if the 95% confidence intervals did not include 1.

RESULTS

Examination of normality revealed that age, height and weight were not normally distributed. Additionally, left rotation and both side bending AROM were not normally distributed. The median range of motion for the cervical spine movements of left side bending was 47°, right side bending 45°, flexion 61°, extension 72°, left rotation 70°, and right rotation 68° (Table 1). The percentile scores for all the AROM movement are presented in Table 2. The majority of the participants (31.6%) scored at the 28 mmHg level on the CCFT, followed by 26.5% of participants scoring at the 30 mmHg level, 20.4% at the 26mmHg level, 17.5% at the 24mmHg level and 4.2% at the 22mmHg level. Of the 122 participants in the study, 45 participants (37%) reported having a previous history of concussion.

Examination of associations with demographic variables revealed that larger body mass was associated with less AROM in the flexion, extension, right and left rotation (rs: -0.27 to -0.39). No significant relationship was observed between AROM and age or height (Table 3).
The findings of this study revealed that there were no significant differences on any of the cervical AROM measures between participants with a history of concussion and those without concussion history (Table 4). Furthermore, the risk of being classified as a low performer did not vary between groups based on concussion history (Table 5).

**DISCUSSION**

Active range of motion measures in adolescent football players in this study were similar to previously reported values in a young adult population. Fair associations were found between AROM and body mass in most directions. Specifically, participants with larger body mass had less AROM in cervical flexion, extension, right rotation, and left rotation.

Adequate active cervical rotation may help with visual scanning and therefore contribute to anticipatory activation of the cervical muscles when playing sports. The authors of this study suggest that young healthy adolescent athletes should be able to rotate their neck through near full range of motion without compensatory motions from elsewhere in the body.

For example, if an athlete falls within the 40th percentile as reported in this study for cervical range of motion a clinician may further examine the causative factors contributing to the decreased motion. There are several reports on cervical AROM values for adults; however information on adolescents is limited. Hence, using adult reference values may be misleading when examining adolescents.

No studies to date have established normative values of clinically measured deep neck flexor endurance for subjects in the age range of 13-18; however, several studies report values for adults with and without neck pain. Specific to the CCFT, a previous investigation reported that asymptomatic young adults (mean age 21.5) had a median baseline assessment score of 24mmHg. In a study of adult patients with neck pain, a lower CCFT score was observed (median pressure score 24 mmHg) compared to as compared to participants without neck pain (median pressure score of 28 mmHg). In this study of high school football players, the median pressure scores for the CCFT were 26mmHg as compared to the ranges previously reported in

| Table 2. Reference values for percentile scores for cervical active range of motion (n = 122) |
|-----------------------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Percentile | 2.5 | 5 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 95 | 97.5 |
| Left side bending (degrees) | 32 | 35 | 40 | 41 | 43 | 45 | 47 | 48 | 50 | 53 | 57 | 60 | 67 |
| Right side bending (degrees) | 32 | 35 | 38 | 40 | 43 | 45 | 45 | 48 | 50 | 52 | 58 | 60 | 63 |
| Flexion (degrees) | 40 | 43 | 45 | 49 | 55 | 59 | 61 | 63 | 67 | 72 | 77 | 80 | 83 |
| Extension (degrees) | 50 | 55 | 59 | 65 | 68 | 70 | 72 | 76 | 79 | 82 | 90 | 93 | 98 |
| Left rotation (degrees) | 55 | 58 | 61 | 63 | 65 | 68 | 70 | 72 | 74 | 77 | 80 | 83 | 87 |
| Right rotation (degrees) | 52 | 58 | 60 | 63 | 65 | 67 | 68 | 70 | 73 | 75 | 78 | 81 | 85 |

| Table 3. Relationship between active range of motion to body mass, height and age of participants |
|-----------------------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| *= statistically significant (i.e.<0.05) | | | | | | | |
| | Body Mass | Height | Age |
| Left Side bending | rs = 0.03, p = .790 | rs = -.052, p = .588 | rs = .121, p = .190 |
| Right Side bending | rs = .016, p = .872 | rs = -.081, p = .402 | rs = .096, p = .299 |
| Flexion | rs = -.272, p = .004* | rs = .072, p = .454 | rs = -.044, p = .638 |
| Extension | rs = -.388, p = .000* | rs = -.127, p = .185 | rs = -.059, p = .524 |
| Left Rotation | rs = -.272, p = .004* | rs = -.153, p = .110 | rs = .019, p = .841 |
| Right Rotation | rs = -.276, p = .004* | rs = -.099, p = .302 | rs = .024, p = .797 |
| Craniocervical flexion test | rs = -.063, p = .566 | rs = -.017, p = .873 | rs = .032, p = .757 |
The findings in this study were different, likely because deep cervical flexor endurance was measured using the CCFT. Collins et al. reported neck strength measured with a hand held tension scale and dynamometers was lower in athletes with concussion than those without concussion and that affordable neck strength assessments are needed in high schools. While specific strengthening programs for the neck have been shown to be effective few are inexpensive and easy to implement. Anticipatory muscular activation is expected to improve the ability of the athlete to brace for an impact.

Eckner et al. demonstrated that linear and angular velocities of the head are reduced when cervical muscles are braced prior to the application of external load; hence bracing may reduce the chances of sustaining concussion. The findings of this study indicate that careful examination of the cervical endurance may be beneficial in athletes who are at risk for cervical injury in a contact sport such as football. Similar to the relationship between decreased cervical endurance in adults with neck pain and whiplash, it may be present after repetitive subclinical head traumas sustained while playing football.

<table>
<thead>
<tr>
<th>Table 4. Comparison of cervical active range of motion (reported in degrees, +/- SD) between participants with and without concussion history.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static, p value</td>
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<tr>
<td>No concussion History</td>
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<tr>
<td>Flexion</td>
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<td>Extension</td>
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<td>Right rotation</td>
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<td>Left rotation</td>
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<td>Right side bending</td>
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<td>Left side bending</td>
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| a = Independent t-test, b = Mann Whitney U test |

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<th>Table 5. Performance classification: Low performer Versus High performer (reference) between concussion and no concussion (reference)</th>
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<tbody>
<tr>
<td>No concussion (low performer/high performer)</td>
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<tr>
<td>Left side bending</td>
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<td>Right side bending</td>
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<tr>
<td>Flexion</td>
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<td>Extension</td>
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<tr>
<td>Left rotation</td>
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<td>Right rotation</td>
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<tr>
<td>Cranio-cervical flexion test</td>
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Note: An odds ratio less than 1 indicate that concussion is associated being classified as a low performer at the given measure. Odds ratio were considered significant if the 95% confidence intervals did not include 1.
The findings of this study indicate that there is no difference in deep cervical flexor endurance and cervical AROM between athletes based on self-reported concussion history. Given the limitations of the cross-sectional design and the inconsistent findings about possible relationship between cervical muscles and concussion, clinicians should interpret these findings cautiously. With the current design, it is not possible to establish the temporal relationship between the concussion incidence and the neck endurance or AROM as these measures could conceivably have changed since injury. A closer inspection of the AROM and the CCFT performance revealed that many adolescent football players had decreased cervical AROM. Furthermore, many of the participants required multiple attempts (up to three) to correctly perform the CCFT without compensatory movements. The cause of these challenges is unknown as the factors that may have contributed to the performance during the CCFT and AROM testing were not explored. It is possible that there is a relationship between the position played and other musculoskeletal impairments could exist.

Participants demonstrated variability in the CCFT as indicated by the frequencies and range of CCFT performance (22mmHg-30mmHg). Additionally, a variability was observed in the AROM performance as indicated in the percentile distribution (Table 2). Therefore, an individualized cervical AROM and the deep cervical flexor endurance assessment is recommended as part of the annual high school physical sport evaluation. If there is decreased AROM or decreased deep neck flexor endurance compared to baseline scores (when available) or percentiles presented in this study, a customized program to improve range of motion and deep cervical flexor endurance should be considered as part of their training. It may be that having an individualized baseline clinical measurement for an athlete may provide meaningful information for that athlete in the event that a concussion or injury to the neck occurs. In practice, the reference values and percentiles presented in this study can be used to assist in the multifaceted clinical decision making process in the management of this population.

Neck pain and dizziness are prevalent symptoms after concussion and despite the lack of association between concussion history and measurements of cervical AROM and deep neck flexor endurance in this study, clinicians should consider performing a screen of both deep neck flexor endurance and cervical AROM. In a study of youth hockey players, Schneider et al suggested that cervical endurance and strength were not predictors of adolescent concussion risk and that other measures may be needed. Similar findings were found in the current study of high school football players. Measures that accurately identify concussion risk factors in the adolescent population are needed, and due to the multifaceted nature of concussion, more comprehensive evaluation may be needed. At a bare minimum, these measures of cervical AROM and endurance can be valuable in the management of concussed athletes.

From a clinical perspective, it can be challenging to justify a cervical screen in the absence of pain; however, with this at risk adolescent population routine tests could be used to identify athletes that may perform in the lower percentiles of performance and consider interventions when appropriate. Screening values could be compared to the reference values provided herein because of the known association of these measures in individuals who have had a whiplash or similar injury. It is possible that that adolescents with concussion may have musculoskeletal impairments that are go unnoticed as neurocognitive and balance symptoms of concussion are typically the primary focus of management that are used to direct and help determine readiness to return to sport. Information about musculoskeletal impairments can be used in the clinical decision making of those working with adolescents who may present with decreased AROM and decreased deep cervical flexor endurance with or without concussion history.

Limitations to the study include the small sample of high school football players which may limit the generalizability to athletes of different gender, age, or sport. Another limitation of the study is the utilization of athlete self-report with regard to having sustained a concussion. It is possible that some of the participants who were classified as healthy may have had unreported or undiagnosed concussions. In this study, only the tests for deep cervical flexor endurance and cervical AROM were explored. Although AROM and deep cervical flexor endurance may be of a value, they do not fully capture the neurodynamic...
aspects of functioning of the cervical muscles. Similar to other regions in the body,\textsuperscript{22} neurodynamic aspects of muscle function such as muscle quickness, rate of force development, and position sense, may be better predictors of functional outcomes and could explain more variance in the concussion outcomes.

**CONCLUSION**

Participants with larger body mass had less AROM in cervical flexion, extension, right rotation, and left rotation than those of lower body mass. There were no statistically significant differences in cervical AROM or DNF endurance in athletes with and without self-reported concussion history. Normative reference values for deep cervical flexor endurance and cervical AROM in high school football players were reported. These reference values can provide useful benchmarks against which the performance of athletes on cervical AROM and deep cervical flexor endurance can be examined.

**REFERENCES**


ABSTRACT

Background: Chronic ankle instability (CAI) is a condition that often develops after repeated ankle sprains, increasing the susceptibility of the ankle to move into excessive inversion when walking on unstable surfaces. Treatment for CAI costs approximately three billion health care dollars annually. Currently, common diagnostic tools used to identify ankle instability are arthroscopy, imaging, manual laxity testing, and self-reported questionnaires.

Purpose: The purpose of this systematic review was to investigate the effectiveness of ultrasonography in diagnosing CAI, in comparison with other diagnostic tools.

Methods: Search limits: articles published between the years 2000-2015, and articles that were peer reviewed and published in the English language. Databases searched: CINAHL, PubMed, Medline, Medline Plus, Science Direct, OVID, Cochrane, and EBSCO. Titles and abstracts of the 1,420 articles were screened for the inclusion criteria by two independent raters, with discrepancies solved by a third rater. The modified 14-point Quality Assessment of Diagnostic Accuracy Studies (QUADAS) scale was used to assess methodological quality of included articles.

Results: Six high quality articles were included in this systematic review, as indicated by high scores on the QUADAS scale, ranging from 10 to 13. Sensitivity of US ranged from: 84.6 % -100%, specificity of US ranged from: 90.9% - 100% and accuracy ranged from: 87% - 90.9%.

Discussion: The results of the included studies suggest that US is able to accurately differentiate between the grades of ankle sprains and between a lax ligament, torn ligament, thick ligament, absorbed ligament and a non-union avulsion fracture. These findings indicate that US is a reliable method for diagnosing CAI, and that US is able to classify the degree of instability.

Conclusion: Researchers found that US is effective, reliable, and accurate in the diagnosis of CAI.

Clinical Implications: US would allow for earlier diagnosis, which could increase the quality of care as well as decrease the number of outpatient visits. This could lead to improvement in treatment plans, goals and rehabilitation outcomes.

level of Evidence: 1a

Keywords: chronic ankle instability, ultrasonography, magnetic resonance imaging

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INTRODUCTION
Chronic ankle instability (CAI) is a condition that often develops after repeated ankle sprains, increasing the susceptibility of the ankle to move into excessive inversion when walking on unsteady surfaces. Approximately 74% of acute ankle sprains result in persistent symptoms (Houston et al., 2014), 30% of which progress to chronic ankle instability.¹ CAI is diagnosed in individuals who report pain and tenderness on the lateral aspect of the ankle, or persistent swelling and discomfort for greater than six months with a history of reinjury or clinical instability of the ankle joint.² ³ In the long-term, CAI can have negative implications on an individual’s participation in recreational activities, as well as occupational duties.²

The primary cause of damage to the structural stability of the ankle joint is trauma by forced inversion and plantarflexion.⁴ The lateral collateral ligaments, which are more commonly affected by acute sprains, include the anterior talofibular ligament (ATFL), the calcaneofibular ligament (CFL), and the posterior talofibular ligament (PTFL). The ATFL is primarily responsible for preventing excessive supination and anterior translation, while also restricting plantar flexion and internal rotation.⁵

Inversion ankle sprains, affecting the lateral ligaments of the ankle, comprise 85% of all ankle injuries.⁶ Lateral ankle sprains are the most common injury occurring in both high school and collegiate athletics, but also affect approximately eight percent of the general population.⁷ ⁸ ⁹

DIAGNOSIS OF CAI
Common diagnostic tools used to identify ankle instability include arthroscopy, imaging, manual testing (like Anterior Drawer Test), and self-reported questionnaires. Arthroscopic examination and magnetic resonance imaging (MRI) are considered the two most accurate methods of diagnosing injuries to lateral collateral ligaments.¹⁰ While arthroscopy allows direct visual access to the intra-articular structures, it is an invasive surgical procedure that could result in serious consequences such as infection or damage to neurologic, vascular, cartilage or ligamentous structures.¹¹ Imaging techniques, which are less invasive than arthroscopy, include MRI, computed tomography (CT) scan, and radiographs. Radiologists use MRI to diagnose CAI due to its ability to visualize damage to the ligaments, as well as surrounding soft tissue structures.¹² The ATFL is best visualized on MRI in an axial view through the level of the malleolar fossa; it will be seen just below the tibiotalar joint. CAI is indicated by a disruption in or thickening of the ligament.¹³ In a retrospective study conducted by Joshy et al., in which 24 patients underwent arthroscopy and MRI of the ankle, MRI was found to have both high specificity (100%) and high sensitivity (100%) for ATFL disruption.¹⁴

The other imaging techniques that are used include radiographs and CT scan. These are the primary imaging techniques used to visualize bony structures and abnormalities. They can also be used to estimate the degree of ankle instability.¹⁵ A radiograph may include an image taken with the ankle placed on stress in order to enhance its ability to detect soft tissue changes.¹⁴

Diagnostic ultrasound works by transmitting sound waves into the tissues through a transducer, which then reflect back to display an image of the tissues. Once an image is produced, a digital caliper is used to measure the length of the ligaments. When imaging the ankle, ultrasound is able to detect synovial lesions, ligamentous injury, and distinguish soft tissue from osseous impingement.¹⁴ Dynamic ultrasound can also be used to discover dislocation of the peroneal tendons, or intrasheath dislocation, which is indicated by an intact retinaculum with subluxation of the peroneal tendons within the groove.¹⁶

Ultrasound has been proven able to detect soft tissue injuries, and has even become the gold standard for the detection of injuries to the patellar and Achilles tendons.¹⁹ Ultrasound is currently being used for diagnosing ligamentous and muscular sports injuries; however, the use of ultrasound and its’ ability to accurately diagnose CAI is still under debate. The purpose of this systematic review is to investigate the effectiveness of ultrasound in diagnosing CAI, in comparison with other diagnostic tools (arthroscopy, imaging, and clinical testing). This will assist rehabilitation professionals to better diagnose and manage cases of CAI.
METHODS
Researchers independently searched English language articles published between the years 2000-2015. Databases searched included CINAHL, PubMed, Medline, Medline Plus, Science Direct, OVID, Cochrane, and EBSCO. Keywords utilized in the search process included ‘chronic ankle instability, ultrasonography, ankle instability, diagnostic imaging, ankle lateral collateral ligament, talofibular ligament and MRI’.

Two independent raters searched each key word set; this initial search resulted in 1,420 articles. The titles and abstracts of the 1,420 articles were screened for the inclusion criteria by two independent raters. In order to be included in the review, the article had to be a diagnostic trial that included comparison between ultrasound and another reference measure (gold standard), to assess chronic lateral ankle instability. When discrepancies occurred between the two independent raters on which articles to include, a third rater made the final decision. Following the screening process, only six articles met inclusion criteria. Figure 1 represents the steps of initially screening titles and abstracts as well as full article review. The quality of each article was assessed by two independent raters using the modified 14-point QUADAS scale. Discrepancies in the raters' findings were resolved by a third rater or by consensus between the two initial raters. The search results are summarized in Table 1 and the methodological quality of included articles is summarized in the following color coded QUADS table (Table 2).

RESULTS
Summary of Included Articles
Lee et al sought to evaluate the effectiveness of stress ultrasonography (US) in comparison with stress radiography and an anterior drawer stress test. Patients with chronic ankle pain or laxity, lasting for at least three months, were included in this study; patients with generalized laxity and acute sprains were excluded from the study. Two foot and ankle surgeons evaluated seventy-three patients. They performed a standardized physical examination including the three tests listed above to assess the integrity of the anterior talofibular ligament (ATFL). A second rater who had no knowledge of the clinical history or the results of the physical examination also evaluated the images. The correlation coefficient between the length of the ATFL on US and...
Table 1. Summary table of search results

<table>
<thead>
<tr>
<th>Authors</th>
<th>Modified 14 point QUADAS score</th>
<th>Study Design</th>
<th>Sample Size</th>
<th>Study Purpose</th>
<th>Diagnostic Procedure</th>
<th>Outcome Measure</th>
<th>Conclusion</th>
</tr>
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<tbody>
<tr>
<td>Yi Cheng, Yehua Cai, Yi Wang</td>
<td>13/14</td>
<td>Prospective comparative study</td>
<td>Total: 120</td>
<td>-Study the effectiveness of ultrasound (US) for diagnosing lateral ankle ligament injuries as compared to arthroscopy.</td>
<td>US: Supine, maximally inverted and plantar flexed. Axial and transverse images were used bilaterally.</td>
<td>The contour and integrity of the ligaments were classified as: grade 0, no injury, grade 1, stretched or swollen ligament without tear, grade 2, partial tear, or grade 3, complete tear of the ligament.</td>
<td>Ultrasoundography accurately identified the grade of injury with a sensitivity of 98.9%, 93.8% and specificity of 96.2%, 90.9% for detecting ATFL and CFL injury respectively.</td>
</tr>
<tr>
<td>Hua, Yang, Chen, Cai</td>
<td>12/14</td>
<td>Prospective comparative study</td>
<td>Total: 83</td>
<td>Determine the value of ultrasound examination of chronic ATFL injuries as compared to arthroscopic findings.</td>
<td>US: Supine, maximum plantar flexion and inversion. Transducer placed along the long axis and then rotated 90 deg.</td>
<td>Ligament tear, Ligament laxity, Thick ligament, Ligament absorbed, Non-union of avulsion fracture of lateral malleolus</td>
<td>Ultrasound examination is reliable and accurate in diagnosing the grade of ATFL injury, indicated by high sensitivity (97.7%) and specificity (92.3%) as compared to arthroscopy</td>
</tr>
<tr>
<td>Gün C, Unlüer EE, Vandenberk N, Karagöz A, Sentürk GO, Oyar O</td>
<td>11/14</td>
<td>Prospective Comparative Study</td>
<td>Total: 65</td>
<td>Accuracy of Bedside Ultrasonography in the diagnosing patients with an ATFL injury compared to MRI.</td>
<td><strong>Bedside Ultrasonography</strong> Positioning: moderate inversion and plantar flexion of the ATFL.</td>
<td>The integrity of the ATFL determined by a torn or abnormal hypoechoic lesion which was confirmed by MRI.</td>
<td>The diagnostic accuracy of BUS and MRI were not significantly different from each other based on findings of 93.8% sensitivity 100% specificity.</td>
</tr>
<tr>
<td>KT. Lee, YU. Park, H Jegal, JW. Park, JP Choi, JS. Kim</td>
<td>11/14</td>
<td>Prospective comparative study</td>
<td>Total: 73</td>
<td>Evaluate the diagnostic value of stress ultrasonography (US) compared to stress radiography in diagnosing patients with chronic ankle instability.</td>
<td>US: Sitting, transducer placed over ATFL and parallel to the sole of foot. Images taken in resting position and maximal stressed position.</td>
<td>US measured the ATFL length at rest and in the maximally stressed position. Anterior displacement of the talus was measured manually by anterior drawer test and mechanically while undergoing Stress radiography.</td>
<td>Stress ultrasound successfully identified the grades of ligamentous injury of the ATFL with a statistical significance of p &lt;0.001. The results were significantly correlated with the data obtained from ADT and were superior to those of stress radiograph.</td>
</tr>
</tbody>
</table>
The grade of the anterior drawer stress test was 0.58. Results indicated that the stress US was able to differentiate between the three grades of the anterior drawer stress test findings. Researchers concluded that stress US is comparable to other conventional methods for diagnosing ligament laxity.\textsuperscript{17}

Hua et al compared ultrasound with arthroscopy, the gold standard for diagnosing chronic ATFL injury.\textsuperscript{15} Their sample consisted of 83 consecutive patients between the ages of 17 and 57 years. The patients all had a preoperative diagnosis of an ankle injury and were examined using diagnostic ultrasound by a senior radiologist with 15 years of experience to determine ligament laxity, ligament tear, ligament width, ligament absorption and/or non-union of avulsion fracture\textsuperscript{15}. The patient was positioned in supine with their ankle in passive maximal inversion and plantar flexion during the ultrasound procedure. All participants then underwent an arthroscopic procedure performed by a sports medicine surgeon who was blind to the ultrasound results.\textsuperscript{15} Forty-four of the patients were diagnosed with an ATFL injury; US was 95.2% accurate in detecting ATFL injury. Hua et al found US to have a sensitivity of 97.7%, specificity of 92.3%, positive predictive value of 93.5%, negative predictive value of 97.3%, positive likelihood ratio (+LR) of 12.7 and negative likelihood ratio (-LR) of 0.025. These results indicate that US findings are likely to assist in diagnosing a patient with ATFL injury.\textsuperscript{15}

<table>
<thead>
<tr>
<th>Table 1. Summary table of search results (continued)</th>
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<tbody>
<tr>
<td><strong>Guiodo, Y., Varache, S., A. Saraux</strong></td>
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<tr>
<td><strong>2010</strong></td>
</tr>
<tr>
<td><strong>10/14</strong></td>
</tr>
<tr>
<td><strong>Prospective Comparative Study</strong></td>
</tr>
<tr>
<td><strong>Total: 56 Men: 46 Women: 10 Mean age: 30.4±10.6 years.</strong></td>
</tr>
<tr>
<td>This article did not provide information about the diagnostic procedures used.</td>
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<tr>
<td>ATFL damage was determined by US, anterior drawer test and CTA. Other details on outcome measures were deficient.</td>
</tr>
<tr>
<td>US is an effective and reliable tool in the diagnosis of chronic ankle instability compared to CTA as demonstrated by a sensitivity of 84.6%, specificity of 100% results were highly correlated with CTA findings (k=0.76).</td>
</tr>
</tbody>
</table>

| **Oae K., Takao M., Uchio Y., Ochi M.** |
| **2010** |
| **10/14** |
| **Prospective Comparative Study** |
| Evaluate the effectiveness of US, stress radiography (X-ray), MRI, and arthroscopy in the diagnosis of ATFL injury |
| US: The ankle was placed in moderate inversion and plantar flexion. |
| US diagnostic criteria: a discontinuation or a hypoechoic lesion that is seen within 5mm from the attachment site. MRI: A discontinuation, a wave or curved contour, and increased signal intensity within the ligament. Arthroscopy: An abnormal course of the ligament with a decrease in the tautness of the ligament or an avulsion at the attachment of the fibula or talus. |
| Ultrasonography and MRI are effective in the diagnosis of ATFL injuries compared to Arthroscopy with an 87% and 93% accuracy, respectively. |
Individuals who had at least six weeks of pain, with or without swelling, and point tenderness over the lateral portion of the ankle on physical examination were included. They chose 120 of these participants who had surgery to be a part of the study.

Cheng et al investigated the effectiveness of ultrasonography (US) in diagnosing lateral ligament injury in comparison with arthroscopy. A sample of 485 patients with a suspicion of lateral ankle ligament injury underwent ultrasonography examination.

<table>
<thead>
<tr>
<th>Table 2. Color Coded Modified 14 Point QUADAS</th>
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<tbody>
<tr>
<td>Modified 14 Point QUADAS Items</td>
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<tr>
<td></td>
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<tr>
<td>2. Is the reference standard likely to classify the target condition correctly?</td>
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<tr>
<td>3. Is the time period between reference standard and index test short enough to be reasonably sure that the target condition did not change between the two tests?</td>
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<tr>
<td>4. Did the whole sample or a random selection of the sample, receive verification using the intended reference standard?</td>
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<tr>
<td>5. Did patients receive the same reference standard irrespective of the index test result?</td>
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<tr>
<td>6. Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)?</td>
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<tr>
<td>7. Were the reference standard results interpreted without knowledge of the results of the index test?</td>
</tr>
<tr>
<td>8. Were the index test results interpreted without knowledge of the results of the reference standard?</td>
</tr>
<tr>
<td>9. Were the same clinical data available when test results were interpreted as would be available when the test is used in practice?</td>
</tr>
<tr>
<td>10. Were uninterpretable/intermediate test results reported?</td>
</tr>
<tr>
<td>11. Were withdrawals from the study explained?</td>
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<tr>
<td>12. Did the study provide a clear definition of what was considered to be a ‘positive’ result?</td>
</tr>
<tr>
<td>13. Had test operators had appropriate training?</td>
</tr>
<tr>
<td>14. Was treatment withheld until both the index test and reference standard were performed?</td>
</tr>
</tbody>
</table>

Table Color Key:

YES: [ Green ]
NO: [ Red ]
NOT CLEAR: [ Yellow ]
Arthroscopy was performed within one week (mean of four days) of ultrasonography. US was performed by a radiologist with seven years of experience and who was blinded to previous physical examination results and diagnoses. Participants were positioned in supine with their foot maximally inverted and plantar flexed. They obtained both axial and transverse sonography of the ligaments. The ligaments were graded individually with a grading scale of grade 0, no injury; grade 1, stretched or swollen ligament without tear; grade 2, partial tear; and grade 3, complete tear of the ligament. Arthroscopy was performed by an experienced surgeon and the same grading system was used. The results of the arthroscopy showed 18 sprains, 52 complete tears and 24 partial tears of the ATFL, 26 sprains, 27 partial tears and 12 complete tears of the CFL and 1 complete tear of the PTFL. The US findings were compared with the surgical findings and the sensitivity of US was found to be 98.9%, and the specificity was 96.2% for diagnosing an ATFL injury. The accuracy of US in diagnosing an ATFL injury was 84.2%. For diagnosing CFL injuries, the sensitivity of US was 93.8%, the specificity was 90.9% and accuracy was 83.3%. Researchers concluded that US is a cost effective and appropriate examination tool for detecting lateral ligament injuries, however, US is dependent on the expertise of the technician and therefore further research should determine criteria for examination and diagnosis.

Gün et al sought to determine the ability of emergency physicians (EPS) to diagnose patients with a history of ankle inversion and suspected ATFL sprain with the use of bedside ultrasonography (BUS). The authors in the study used MR imaging as the reference standard. (The EPS received three hours of didactic training and three hours of hands-on training by a radiologist in order to perform ultrasonography on the ankle joint and diagnose possible AFTL injury. Sixty-five patients (37% females), with a mean age of 34.03 ± 12.85, ranging from 18 to 72 years of age participated in the study. Participants with suspected inversion and chronic ankle injury were included in the study. Patients with fractures and open wounds around the ankle were excluded. During the BUS, the ligaments were determined to be ruptured if they were not depicted as hypoechoic bundles, indicated by a discontinuation of the bundles. In comparison with MRI, researchers found BUS to have a sensitivity of 93.8%, CI: 79.2-99.2, a specificity of 100%, CI: 89.4-100, a positive predictive value of 100, CI: 88.4-100, and a -LR: 0.06. Researchers determined that the difference between the diagnostic accuracy of BUS and MR imaging was not statistically significant (K=0.938, p = 0.001). This indicates that BUS can be a diagnostic tool to help with early and prompt diagnosis of ankles that have experienced acute trauma.

Oae et al sought to evaluate the diagnostic value of radiographic examination, ultrasonography, and MR imaging in diagnosing ATFL injury in comparison with arthroscopy, the reference standard. This prospective study included 34 patients in need of an operation to correct an osteochondral lesion, synovitis, or instability. There were 19 males and 15 females with a mean age of 29 years, ranging from 13 to 55 years. Nineteen patients had acute ankle injuries, while 15 participants had chronic injuries. Patients were excluded from the study if they were determined to be in the subacute phase or have a fracture. A separate blinded author, who had 10 years of experience in diagnosing musculoskeletal and orthopedic conditions, examined the images. This evaluator was blinded specifically to the participants' history and physical examination. The ankle arthroscopy was performed after the imaging examinations. For each diagnostic test, there were slight variations in the criteria for a positive diagnosis of a torn ATFL. On stress radiograph, the amount of anterior displacement from the talus to the posterior lip of the tibia was measured. A difference of three mm. or greater was considered to be a positive test, indicating lateral instability. The diagnostic criteria for ligament injury on US were discontinuity and hypoechoic lesion of the AFTL. On MR imaging, discontinuity, a wavy or curved contour, and increased signal intensity within the ligament indicated ligament injury. The reference standard classified a ligament injury by an abnormal course of the ligament, a decrease in the tautness of the ligament, and an avulsion at the attachment of the fibula or talus. Using ankle arthroscopy, 30 of the 34 patients were positive for an ATFL injury. Compared to the reference standard, the stress radiography had a 71% accuracy rate, US had a 91% accuracy rate, and MR imaging had a 97% accuracy. After com-
paring these diagnostic tests to the reference standard, the authors believe that US and MR imaging has satisfactory results when reporting ATFL injury. Based on the data, MR imaging has a higher specificity than US in locating the area of ligament injury. The authors comment that one of the limitations of the study is that arthroscopy is unable to detect intraligamentous partial tears, but when using US, examiners can detect intraligamentous tears. This may have influenced whether or not a ligament was considered torn and reflected as differences in the results between US and arthroscopy.  

Guillodo et al evaluated the value of ultrasonography in diagnosing ATFL injury in patients with CAI in comparison to computed arthrotomography (CTA). The ages of participants ranged from 15 to 69 years (mean, 30.1 ± 10.6 years). Inclusion criteria of this study were athletes with ankle injury symptoms (persistent pain and/or instability) present for approximately three months and athletes who were prohibited from participation in sports. Anterior drawer stress test and US were performed by the same sports medicine specialist who had 20 years of experience working with sports medicine and US. The CTA was conducted in the same radiological center using a standardized protocol. Thirty-two out of the 56 patients had a positive anterior drawer test, 34 out of 56 patients had evidence of clinical laxity on US, while CTA found evidence of ATFL injury in 39 out of 55 patients. The reference standard gathered inconclusive results with one patient. When comparing CTA to US, the kappa value reported was k = 0.76. The sensitivity, specificity, positive predictive value, and negative predictive value for US compared to CTA were 84.6% (33/39), 100% (16/16), 100% (33/33), and 72.7% (16/22), respectively. This study concluded that US can be used after a radiographic assessment for athletes with chronic ankle instability.

DISCUSSION

The purpose of this systematic review was to investigate the effectiveness of ultrasonography (US) in diagnosing CAI, in comparison with other diagnostic tools. The results indicate that US is a valuable diagnostic tool for chronic ankle instability in all six of the studies that were analyzed, demonstrating high sensitivity and specificity when compared to various reference standards. The summary table reveals that all six articles included in this systematic review came to the same conclusion: US is an effective diagnostic tool in detecting chronic ankle instability (CAI). The table shows statistical data that reveals high inter observer agreement, high sensitivity, high specificity, and high positive likelihood ratios, which together indicate that US is an effective diagnostic tool.

The reference standards used to measure the effectiveness of US included arthroscopy in three studies, MRI in two studies, stress X-Ray in one study, anterior drawer stress test in one study, and CTA in one study. These tools have all been used to diagnose CAI, and are therefore appropriate reference standards for determining the reliability and accuracy of US. The sample sizes ranged from 34 to 120 participants, with all of the studies having more males than females. All of the studies had samples that were considered to be representative of the target population. US examinations in the studies were performed in some degree of inversion and plantarflexion, using moderate to maximal stresses. One study also obtained images with the ankle in the resting position, and one study did not disclose specifics of test positioning. Damage to the anterior talofibular ligament (ATFL) was identified by various criteria in the studies, including interruption of the ligament, laxity of the ligament, hypoechoic lesions in the ligament, ligament thickening, and absorption of the ligament.

In comparison with arthroscopy, the highest quality reference standard, US had a sensitivity of 98.9% and 97.7% and specificity of 96.2% and 92.3%. Oae et al also found US to have an 87% accuracy rate (sensitivity), when measured against arthroscopy. In comparison with MRI, US had a sensitivity of 93.8% and specificity of 100%. The research performed by Cheng et al was the only study included in the systematic review that looked at all three ligaments of the lateral ankle and not just the ATFL. Their results still demonstrated high specificity and sensitivity results for the use of US in diagnosing ATFL injury.

Question three on the QUADAS table inquires about the time period between the performance of
diagnostic US and the reference standard. In five out of the six articles, the researchers did not clearly state the time that transpired between diagnostic imaging tests, resulting in the classification of unclear. If the tests were performed with a greater amount of time between them, it is possible that the condition of the ligaments could have worsened or changed to some degree, which would decrease the internal validity of the study. In addition, five out of the six articles were unclear with regard to question 14 that related to determining whether treatment was withheld until both diagnostic imaging tests were performed. This piece of information is critical because treatment can influence the structural representation of the ligaments.

ULTRASOUND VALUE WITH CHRONIC ANKLE INSTABILITY

The outcome measures used to assess the integrity of the ATFL on US included a four point grading scale, the presence of hypoechoic lesions, disruption of ligamentous continuity, or laxity. Examiners’ interpretations of US images, using these grading systems, resulted in high sensitivity, specificity, and accuracy for US when compared to the reference standards throughout all six articles. All possible tools used to clinically diagnose CAI were compared with US and US was deemed effective in correctly diagnosing ankle instability.

In concordance, Tourne et al.22 stated that the primary use of diagnostic US at the ankle is in the dynamic evaluation of the lateral collateral ligaments. The authors also state that it can be helpful in the identification of anterolateral impingement, but that it is not useful in assessing bone or cartilage. Unlike other diagnostic tools, US allows for a real-time visualization of the ATFL. This is important because this allows an examiner to differentiate between the grades of instability, and to accurately localize the injury. US is a valuable tool in the diagnosis of CAI because it is cost effective, it does not expose the patient to radiation, and it is efficient, and noninvasive.23 Although US is known to be operator dependent, according to the study performed by Gun et al.,19 emergency physicians were taught how to use and diagnose CAI of the ATFL with US in six hours of training by a radiologist. The inter observer agreement was high and the emergency physicians were able to accurately diagnosis CAI of the ATFL. This implies that although US is operator dependent, it does not take an extensive amount of time to learn and master the diagnostic skills.19

ACCURACY IN DIAGNOSING DEGREES OF INSTABILITY

US not only detects injury to the ATFL, but it can also classify the degrees of instability. According to the study performed by Hua et al.15AFTL injury was classified by US as “(i) ligament tear: a partial or total interruption of the ligament fibers at the fibular side, talar side or in the mid stance; (ii) lax ligament: the ligament remained curved when the ankle was in the maximum inversion and plantar flexion; (iii) thick ligament: the width of the ligament was > 24 mm or > 20% of the contralateral normal ligament; (iv) pigment absorbed: no ligament fibers were seen; and (iv) non-union of avulsion fracture of the lateral malleolus”.15 The ability of US to classify the grade of injury indicates the severity of damage to the ankle, allowing for a more specific diagnosis. With more accurate diagnosis, therapists can create more appropriate goals, treatment plans, and may be better able to predict the prognosis for a patient.

Many of the studies included in this systematic review utilized an anterior draw stress test as one of the comparative diagnostic tools. The anterior draw test is a diagnostic tool that entry-level physical therapists are taught to perform, and it is successful in diagnosing injuries to the ATFL. In the study conducted by Guillodo et al.,21 the anterior draw stress test had a kappa value of 0.62 and US had a kappa value of 0.76, when compared to computed athrotopography (CTA).21 These values demonstrate that US has a higher inter observer agreement than the anterior drawer stress test. Also, US was accurate in successfully differentiating different grades of ATFL injuries according to Cheng et al.18 The anterior drawer stress test can be used to determine an injury to an ankle with accuracy but it is not as capable at determining the severity of tissue injury. In a clinical setting, it is pertinent for the therapist to have the ability to determine not only the presence but also the severity of the injury in order to decide when a patient is a candidate for physical therapy.
interventions or a referral for possible surgery. US offers this acuity when evaluating the grade of injury to a patient’s ligaments and can provide excellent information for the clinician related to decision making when determining the best possible plan of care for the patient.

One study, performed by Margetic & Pavic found a discrepancy between US and MRI in the ability to decipher the grade of the ligamentous injury. US was able to diagnose considerably more ligament sprain injuries than MRI, while MRI was able to diagnose significantly more complete ligament ruptures than US. The authors concluded that MRI should always be consulted to confirm the need for surgical treatment. Talijanovic et al described the anatomy of the lateral aspect of the ankle, focusing on the peroneal tendon, and current imaging tools to identify normal anatomy and detect injuries. The researchers concluded that dynamic US is the best imaging technique for the evaluation of peroneal tendon subluxation and/or dislocation.

VALUE OF US TO PT
The knowledge of US and its diagnostic capability is extremely beneficial to the profession of physical therapy. As mentioned, physical therapists can use the results from US images to create treatment plans, goals, and to assist with predicting the patients’ prognosis and outcomes. Physical therapists could implement specific treatment protocols because they will have definitive information to choose appropriate interventions specific to the type and extent of injury experienced by the patient. By identifying the grade of injury, physical therapists can choose interventions tailored specifically to the patient’s injury and phase of healing, leading to more efficient and effective treatment.

The use of US is part of the future of the Physical Therapy practice. It will increase the quality of care and allow for a decreased number of outpatient visits because the diagnosis will accurately reveal the injury severity and location. Also, the efficiency of US allows for early diagnosis of CAI, which minimizes the risk of mechanical and functional instability over time. Early detection can also help delay or accelerate the need for invasive surgery based upon the severity of the injury.

TRAINING
In the study by Gun et al, bedside US examiners had six hours of training before they examined the participants included in the emergency department. With such limited amount of training, these examiners were able to accurately identify 30 true positives, and 33 true negatives. There were zero false positives, and two false negatives. This is a promising finding, as it appears that with minimal training examiners can accurately assess suspected ATFL injuries using US. Therapists are encouraged to investigate the use and the benefits of using US in PT clinics. Cost effectiveness as well as time needed to ensure adequate learning regarding the use of US machines by therapists should be investigated.

CONCLUSION
The results of the this systematic review indicate that US is a highly sensitive, specific, and accurate imaging technique that can be used to diagnose lateral ankle injury and CAI. The addition of US as part of physical therapy examination will allow for an accurate initial evaluation, excellent treatment, and improved discharge planning. Such outcomes represent a better quality care for patients and an evidence based shift of the profession towards improved patient diagnosis and management.

REFERENCES


ABSTRACT

Background: In spite of the bodyblade (BB®) being used in clinical settings during shoulder and trunk rehabilitation and training for 24 years, there are only five known scientific papers that have described muscle recruitment patterns using the BB®. Moreover, there are no known studies that have examined muscle activity differences between males and females (who both use the bodyblade in the clinic) or between different BB® devices.

Hypothesis/Purpose: The primary purposes of this investigation were to compare glenohumeral and scapular muscle activity between the Bodyblade® Pro (BB®P) and Bodyblade® Classic (BB®C) devices while performing a variety of exercises, as well as to compare muscle activity between males and females. It was hypothesized that glenohumeral and scapular muscle activity would be significantly greater in females compared to males, significantly greater while performing exercises with the BB®P compared to the BB®C, significantly different among various BB® exercises, and greater with two hand use compared to one hand use for the same exercise.

Study Design: Controlled laboratory study using a repeated-measures, counterbalanced design.

Methods: Twenty young adults, 10 males and 10 females, performed seven BB® exercises using the BB®C and BB®P, which are: 1) BB®1 - one hand, up and down motion, arm at side; 2) BB®2 - one hand, front to back motion, shoulder flexed 90°; 3) BB®3 - one hand, up and down motion, shoulder abducted 90°; 4) BB®4 - one hand, side to side motion, shoulder and elbow flexed 45°; 5) BB®5 - two hands, side to side motion, shoulders and elbows flexed 45°; 6) BB®6 - two hands, up and down motion, shoulders flexed 90°; and 7) BB®7 - two hands, front to back motion, shoulders flexed 90°. EMG data were collected from anterior and posterior deltoids, sternal pectoralis major, latissimus dorsi, infraspinatus, upper and lower trapezius, and serratus anterior during 10 sec of continuous motion for each exercise, and then normalized using maximum voluntary isometric contractions (MVIC). A two-factor repeated measures Analysis of Variance (p < 0.05) was employed to assess differences in EMG activity between BB® devices (BB®C and BB®P) and genders.

Results: As hypothesized, for numerous exercises and muscles glenohumeral and scapular EMG activity was significantly greater in females compared to males and was significantly greater in the BB®P compared to BB®C. There were generally no significant interactions between BB® devices and gender. Overall glenohumeral and scapular muscle activity was significantly greater in BB®3 and BB®6 compared to the remaining exercises, but generally not significantly different between using one hand and using two hands.

Conclusions: It may be appropriate to employ BB® exercises during shoulder rehabilitation earlier for males compared to females and earlier for the BB®C compared to the BB®P given less overall muscle activation in males and BB®C compared to in females and BB®P. There was generally no difference in muscle activity between performing the BB® with one-hand or two-hands. Differences in muscle activity between exercises generally was the similar regardless if the BB®C or the BB®P was employed.

Level of Evidence: Level 2

Key Words: Electromyography, oscillation exercises, sports rehabilitation, vibration exercises

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INTRODUCTION

The Bodyblade® (BB®) (Mad Dogg Athletics®, Inc, Venice CA) is an exercise device based on oscillatory/vibration motions that has been used in training or rehabilitation since its 1991 invention. The BB® works by rapidly changing directions at a low frequency rhythm of approximately 4.5 Hz (cycles per second). As a result, the body reacts 270 times per minute to resist the rapid destabilizing forces of the blade sweeping back and forth by continually changing directions. Moreover, the resistance needed to control the blade may vary considerably depending on the size and oscillatory speed of the blade.

There are various models of the BB® used in rehabilitation and training, such as the BB® Pro (BB®P), BB® Classic (BB®C), and BB® CxT listed from heaviest, longest, and most difficult to perform to lightest, shortest and easiest to perform, respectively. Anecdotally the most common models used in the physical therapy clinic is the BB®P, with a mass of approximately 1.14 kg and a length of approximately 152 cm, and the BB®C, with a mass of approximately 0.68 kg and a length of approximately 122 cm. Used to a lesser degree in the clinic is the BB® CxT (0.57 kg, 101.6 cm).

The BB® is different than traditional resistance training, such as traditional free weights involving concentric and eccentric movements, in that it can be performed with or without joint motion. Once oscillating, the BB® can be moved in a variety of positions and movement patterns. It can be kept in a quasi-static position for a prolonged period of time as it oscillates, or it can be moved dynamically throughout varying shoulder and elbow ranges of motion as it oscillates. The BB® is commonly used by physical therapists for rehabilitation and training of athletes at all levels, and by many others who are interested in enhancing health and fitness. The two regions of the body most commonly targeted by the BB® are the shoulder complex and the trunk (core) region. Both shoulder prime movers (eg, pectoralis major, latissimus dorsi, and deltoids) and stabilizers (eg, infraspinatus, supraspinatus, subscapularis) of the glenohumeral joint are important because the glenohumeral joint is an inherently unstable joint that depends heavily on dynamic stabilizers for stability. Scapular muscles such as the serratus anterior, upper trapezius, middle trapezius, and lower trapezius are also important for normal scapulohumeral rhythm. Decreased scapular upward rotation and posterior tilt during arm elevation have been shown to increase subacromial impingement risk. The primary scapular muscles that help stabilize the scapula and properly position the scapula on the thorax during arm elevation (such as overhead throwing) are the serratus anterior, upper trapezius, and lower trapezius.

Physical therapists use the BB® believing that their patients derive multiple benefits, such as improved wellness, enhanced functional stability, improved muscle tone, improved endurance, enhanced proprioception, increased strength, greater power, improved core stability, enhanced coordination, improved balance, better flexibility, enhanced posture, increased efficiency of muscle function, aerobic improvement, increased metabolism, and weight loss. In spite of all of these proposed benefits and the relatively common use of the BB®, scientific support for the efficacy of the BB® is scarce. Over the 24 years the BB® has been in use in clinical settings, there have only been seven known papers that have been published in the scientific peer reviewed literature (PubMed and SportDiscus search engines). Of these seven papers only five quantified shoulder or trunk muscle activity while performing the BB®. Arora et al quantified muscle activity from select shoulder and trunk muscles between a double oscillating device (BB®C) and a single oscillating device (FlexBar®, Hygenics Corporation, Akron, Ohio). The BB®C provided 35.9%, 40.8%, and 52.3% greater activity in the anterior deltoid, transverse abdominis/internal oblique, and lumbo-sacral erector spinae, respectively, compared to the FlexBar. Moreside et al primarily analyzed trunk EMG muscle activation patterns as well as spine kinematics and lumbar compressive forces during a variety of exercises involving the BB®C. These authors reported that the posture of the user, the position and orientation of the blade, and the amplitude of the oscillations determined which specific muscle(s) are used and how much they are activated. They reported that activation of the internal and external obliques was significantly greater with large amplitude oscillations compared to small amplitude oscillations, with a two-hand position compared to a one-hand posi-
tion, and with a vertical blade orientation compare to a horizontal blade orientation.

Parry et al\textsuperscript{6} reported greater shoulder and trunk EMG muscle activity during shoulder flexion and abduction exercises using the BB\textsuperscript{P} compared to exercise using dumbbells, while Lister et al\textsuperscript{4} reported greater upper trapezius, lower trapezius, and serratus anterior activities during shoulder flexion and abduction exercises using BB\textsuperscript{P} exercises compared to exercises using cuff weights and elastic resistance bands. Finally, Oliver et al\textsuperscript{5} reported moderate to moderately strong upper and lower extremity muscle activity while performing a variety of shoulder rehabilitation exercises using the BB\textsuperscript{C}.

There are only two known papers in the literature that quantify EMG muscle activity using the BB\textsuperscript{C} and two known papers that quantify muscle activity using the BB\textsuperscript{P}. Even though the BB\textsuperscript{P} and BB\textsuperscript{C} are both commonly used in clinical settings by both men and women, there are no known studies that have compared shoulder muscle activity between these two exercise devices. It is unknown if shoulder muscle recruitment patterns differ between the BB\textsuperscript{P} and BB\textsuperscript{C}. It is also unknown what population, such as males versus females or young vs old, is best suited for use of the BB\textsuperscript{P} and BB\textsuperscript{C} in rehabilitation and training. There is only one study in the scientific literature that used females to quantify shoulder or trunk muscle activity while performing the BB\textsuperscript{C}, however this study did not analyze the effects related to gender.\textsuperscript{12}

The primary purposes of this investigation were to compare glenohumeral and scapular muscle activity between the BB\textsuperscript{P} and BB\textsuperscript{C} devices while performing a variety of exercises, as well as to compare muscle activity between males and females. A secondary purpose of this study is to compare glenohumeral and scapular muscle activity between different BB\textsuperscript{P} exercises.

The hypotheses were:

1) Glenohumeral and scapular muscle activity will be greater in females compared to males; with the assumption that females will be working their muscles at a higher percent of their maximum effort.

2) BB\textsuperscript{P} because the BB\textsuperscript{P} is heavier and longer than the BB\textsuperscript{C} and may be more difficult to handle, thus, glenohumeral and scapular muscle activity will be greater while performing exercises with the BB\textsuperscript{P} compared to performing the same exercises with the BB\textsuperscript{C}.

3) Glenohumeral and scapular muscle activity will be significantly different among BB\textsuperscript{P} exercises given the movement patterns will occur in different planes and body positions when using the BB\textsuperscript{P}, and given some exercises will involve using only one hand and some exercises will involve using two hands while performing the BB\textsuperscript{P}.

4) Glenohumeral and scapular muscle activity will be significantly greater using the BB\textsuperscript{P} with two hands compared to performing the same pattern and movement BB\textsuperscript{P} exercise with one hand.

**METHODS**

**Subjects**

A convenience sample of 20 relatively young adults, 10 males (29±8 y.o., 84±12 kg, 181±5 cm) and 10 females (27±5 y.o, 62±8 kg, 169±5 cm), participated in this study. All subjects provided written informed consent in accordance with the Institutional Review Board at Baptist Hospital and California State University, Sacramento. To standardize experience and familiarity with the BB\textsuperscript{P}, subjects were chosen that had no prior experience using the BB\textsuperscript{P}. All subjects had to be able to perform all exercises pain-free with proper form and technique for the full duration of each exercise; otherwise they were excluded from the study. Inclusion criteria involved all subjects being between 18-39 years old. A younger population was chosen for this study and subjects were recruited by word of mouth and flyers throughout the Sacramento, CA region.

**Exercise Descriptions**

The BB\textsuperscript{P} and BB\textsuperscript{C} devices (Figure 1) were used to perform seven different exercises. The exercises are shown and described in Figures 2-8. Both one-handed exercises (Figures 2-5) and two-handed exercises (Figures 6-8) were used and the BB\textsuperscript{P} exercises were performed in all three planes of motion and in a variety of body positions. The exercises were cho-
Proper exercise form and technique while performing each exercise was demonstrated and explained by the senior author. Each subject then performed each exercise, with the senior author providing feedback as appropriate. This process continued multiple times during the week until the senior author checked-off that proper form and technique were appropriate for each exercise. Data collection occurred within one week of becoming acclimated and familiar with all exercises.

Data Collection

Subject preparation and electrode placements

Subjects wore shorts, shoes, and no shirt (sports bra for females) for testing. Prior to applying the electrodes,
EMG Normalization

Once the electrodes were positioned on the subject's dominant side, the subjects warmed up by stretching, calisthenics, and light to moderate isometric muscle contractions from the muscles being assessed, with the objective being to simply warm up and not fatigue. EMG data were then collected during two five second maximum voluntary isometric contractions (MVIC) for each muscle according to standardized manual muscle testing positions described by Hislop and Montgomery. Between each MVIC the subject rested approximately one minute in order to minimize the effects of fatigue. The MVIC's for each muscle were performed in a randomized order for each subject.

EMG Equipment

EMG data were sampled at 1000 Hz using a Noraxon Telemyo electromyography (EMG) system (Noraxon USA, Inc., Scottsdale, AZ). The EMG amplifier band-pass frequency was 10-500 Hz with an input impedance of 20,000 kΩ, and the common-mode rejection ratio was 130 dB.

Electrode pairs were then positioned on the skin over eight glenohumeral and scapular muscles on each subject's dominant side as previously described. The senior author has 25 years experience in EMG methodology, skin preparation, and electrode placement, and he performed all of the EMG preparation for all subjects. Electrodes were positioned over eight glenohumeral and scapulothoracic muscles as described in Table 1.

Figure 4. BB°C3 (BB°C3 and BB°P3). Performed with one hand at approximately 90° abduction using small quick superoinferior oscillations due to small shoulder abduction/adduction movements as the Bodyblade® moves back and forth in a sagittal plane.

Figure 5. BB°C4 (BB°C4 and BB°P4). Performed with one hand with shoulders and elbows flexed approximately 45° using small quick mediolateral oscillations due to small horizontal abduction/adduction movements with elbow slightly bent as the Bodyblade® moved back and forth in a frontal plane.
tion for exercise trials less than 15 sec.\textsuperscript{6} Using a combination of 12 second oscillation for each exercise and providing approximately a 1 to 10 work to rest ratio minimized any fatigue effects.

**Bodyblade Exercises**

After the MVIC’s were completed, the subject performed a brief warm-up using the BB\textsuperscript{P} and BB\textsuperscript{C} while performing the exercises that were used in testing. Once warm up was achieved each subject performed seven exercises with the BB\textsuperscript{P} and the same seven exercises with the BB\textsuperscript{C} (Figure 2-8) for a total of 14 exercise trials. The 14 exercise trials were each performed for 12 seconds and were performed in a randomized order. Data collection began two seconds after the subject started the exercise and continued for 10 seconds of continuous motion. Between each exercise the subject rested approximately two minutes.

Although it has been recommended that an individual resist BB\textsuperscript{*} oscillations for 60 seconds, pilot studies indicated that most novices begin to fatigue at approximately 15 seconds which provided justifica-

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{image1}
\caption{BB\textsuperscript{5} (BB\textsuperscript{C5} and BB\textsuperscript{P5}). Performed with two hands with shoulders and elbows flexed approximately 45° using small quick mediolateral oscillations due to small horizontal abduction/adduction movements with elbow slightly bent as the Bodyblade\textsuperscript{*} moved back and forth in a frontal plane. Also known as the “Hip and Thigh Sculptor” on the Bodyblade\textsuperscript{*} website (www.bodyblade.com).}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{image2}
\caption{BB\textsuperscript{6} (BB\textsuperscript{C6} and BB\textsuperscript{P6}). Performed with two hands at approximately 90° flexion using small quick superoinferior oscillations due to small shoulder flexion/extension movements with the elbow slightly bent as the Bodyblade\textsuperscript{*} moves back and forth in a frontal plane. Also known as the “Ab Crunch” on the Bodyblade\textsuperscript{*} website (www.bodyblade.com).}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{image3}
\caption{BB\textsuperscript{7} (BB\textsuperscript{C7} and BB\textsuperscript{P7}). Performed with two hands at approximately 90° flexion using small quick anteroposterior oscillations due to small elbow flexion/extension movements as the Bodyblade\textsuperscript{*} moves back and forth in a transverse plane. Also known as a “chest press”. Also known as the “Chest Pass” on the Bodyblade\textsuperscript{*} website (www.bodyblade.com).}
\end{figure}
One-way repeated measures Analysis of Variance was employed (p < 0.05) to assess differences in EMG activity among the seven exercises. The Holm-Bonferroni Sequential Correction\(^1\) was employed to control the familywise Type I error rate secondary to multiple comparisons by adjusting the p-values while keeping an alpha of 0.05 constant. Post-hoc Bonferroni t-tests (p < 0.05) were used to assess pairwise comparisons.

**RESULTS**

**Gender: Males vs. Females**

Significant differences in normalized EMG activity were found (Table 2) between males and females when data were collapsed across the two BB\(^6\) devices (BB\(^6\)C and BB\(^6\)P). Compared to males, females exhibited significantly greater anterior deltoid and serratus anterior activity during all exercises except BB\(^6\) and BB\(^7\), and significantly greater latissimus dorsi activity during all exercises except BB\(^1\) and BB\(^4\).

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**Data Processing**

As previously reported,\(^1\) raw EMG signals were full-waved rectified, smoothed with a 10 ms moving average window, linear enveloped over the duration of the 10 sec trial, and then normalized by expressing the exercise data as a percentage of each subject’s highest corresponding MVIC trial. From the two 5 second MVIC trials for each muscle, the highest EMG signal over a one second time interval was determined to calculate MVIC trials.\(^1\) The resting EMG values for each muscle from the resting EMG trial represented baseline activity for each muscle and was used to “zero” muscle activity during each exercise and MVIC trial.\(^1\)

**Statistical Analysis**

A two-way (2 x 2) repeated measures Analysis of Variance was employed (p < 0.05) to assess differences in EMG activity between the two BB\(^6\) devices (BB\(^6\)C and BB\(^6\)P) and gender (male and female).
Table 2. Male versus female comparisons collapsed across BB®C and BB®P exercises - average EMG ± SD, expressed as a percent of each muscle’s maximum isometric voluntary contraction, for each muscle and exercise.

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<th>Exercise</th>
<th>Subjects</th>
<th>Anterior Deltoids</th>
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*EMG activity significantly different (p < 0.05) between males and females
BB®C = Bodyblade® Classic
BB®P = Bodyblade® Pro

Compared to males, females exhibited significantly greater sternal pectoralis major activity during BB®1, BB®2, and BB®3, significantly greater upper trapezius activity during B1 and B4, and significantly greater infraspinatus activity during B1. There were no significant differences between males and females in posterior deltoid and lower trapezius activity for any of the exercises.

**Devices: BB®C vs. BB®P**

Significant differences in normalized EMG activity were found between BB® devices (BB®C and BB®P) when collapsed across gender (Table 3). Compared to BB®C, BB®P exhibited significantly greater anterior deltoid activity during BB®2, BB®3, BB®4, and BB®6, and significantly greater posterior deltoid activity during BB®3, BB®4, and BB®6. Compared to BB®C, BB®P exhibited significantly greater sternal pectoralis major activity during BB®3, BB®4, and BB®5, and significantly greater infraspinatus activity during BB®2, BB®3, and BB®4. Compared to BB®C, BB®P exhibited significantly greater upper trapezius activity during BB®3, significantly greater lower trapezius activity during BB®3 and BB®4, and significantly greater serratus anterior activity during BB®2, BB®3, BB®6, and BB®7. There were no significant differences between BB®C and BB®P in latissimus dorsi activity for any of the exercises.

**Device x Gender Interactions**

There were generally no significant interactions between BB® devices and gender with the exception
activity during BB®P4 (21±8% of MVIC) compared to BB®C4 (14±7% of MVIC), while there was no significant difference in posterior deltoid activity in females between BB®P4 (27±18% of MVIC) and BB®C4 (27±19% of MVIC).

Comparisons in Muscle Activity Among Exercises

Muscle activity comparisons among exercises are shown in Table 4. Anterior and posterior deltoid, latissimus dorsi, upper and lower trapezius, serratus anterior, and infraspinatus activity was greatest in BB®3 compared to the other exercises. Anterior and posterior deltoid activity was generally greatest in BB®2, BB®3, and BB®6 and least in BB®1. Sternal pectoralis major was generally greatest in BB®4 and BB®5 and similar among the remaining exercises. Latissimus dorsi activity was greatest in BB®1 and BB®3 and similar among the remaining exercises. Upper and lower trapezius was greatest in BB®3 and BB®6 and

Table 3. BB®C versus BB®P comparisons collapsed across Gender - average EMG ± SD, expressed as a percent of each muscle's maximum isometric voluntary contraction, for each muscle and exercise.

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<th>Exercise</th>
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*EMG activity significantly different (p < 0.05) between BB®P and BB®C
BB®C = Bodyblade® Classic; BB®P = Bodyblade® Pro

of the following muscles: infraspinatus (p = 0.001; F = 15.030), sternal pectoralis major (p = 0.047; F = 4.872), and posterior deltoid (p = 0.024; F = 6.268) during BB®4 and the infraspinatus (p = 0.022; F = 6.564) during BB®6. Males exhibited significantly greater infraspinatus activity during BB®P4 (35±17% of MVIC) compared to BB®C4 (24±15% of MVIC) and during BB®P6 (39±18% of MVIC) compared to BB®C6 (34±18% of MVIC), while there were no significant differences in infraspinatus activity in females between BB®P4 (27±18% of MVIC) and BB®C4 (27±19% of MVIC).
DISCUSSION

This is the first known study that has compared muscle activity between males and females while performing exercises with the BB® device, and only the second known study that used females as subjects while using the BB®. The hypothesis that glenohumeral and scapular muscle activity would be greater in females than males was partially supported by the data. Females having to work at a higher relative intensity compared to males and thus demonstrating greater muscle activity is not surprising when using the BB® given their smaller stature and relative strength. Although muscle activity in females was higher compared to males in nearly all exercise and muscle comparisons, significant differences in muscle activity only occurred in 38% of the exercise and muscle comparisons (Table 2). The muscles that exhibited the greatest differences in muscle activity between males and females were the anterior deltoid, latissimus dorsi, and serratus anterior, which were significantly greater in females compared to males in five out of the seven BB® exercises. In contrast, muscle activity in the posterior deltoid and lower trapezius was not significantly different between males and females in any of the seven BB® exercises. Why females tend to use some muscles more than other muscles to a greater extent compared to their male counterparts during performance of the exercises included in this study is beyond the scope of this investigation. Further research is warranted in order to draw any further conclusions.

The hypothesis that glenohumeral and scapular muscle activity would be greater in the BB®

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Table 4. Muscle activity comparisons among exercises - average EMG ± SD, expressed as a percent of each muscle's maximum isometric voluntary contraction, for each muscle and exercise.

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<thead>
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<th>Exercise</th>
<th>Anterior Deltoids*</th>
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<td>36±14</td>
<td>37±18</td>
</tr>
<tr>
<td>BB®3 (Figure 4)</td>
<td>47±22</td>
<td>18±13</td>
<td>10±5</td>
<td>22±16</td>
<td>22±14</td>
<td>26±14</td>
<td>36±14</td>
<td>37±18</td>
</tr>
<tr>
<td>BB®4 (Figure 5)</td>
<td>18±13</td>
<td>22±14</td>
<td>31±11</td>
<td>19±13</td>
<td>14±11</td>
<td>28±22</td>
<td>23±15</td>
<td>34±15</td>
</tr>
<tr>
<td>BB®5 (Figure 6)</td>
<td>26±16</td>
<td>17±9</td>
<td>37±13</td>
<td>20±14</td>
<td>18±11</td>
<td>28±17</td>
<td>35±18</td>
<td>24±13</td>
</tr>
<tr>
<td>BB®6 (Figure 7)</td>
<td>40±19</td>
<td>23±15</td>
<td>18±6</td>
<td>22±17</td>
<td>40±19</td>
<td>35±21</td>
<td>43±13</td>
<td>38±15</td>
</tr>
<tr>
<td>BB®7 (Figure 8)</td>
<td>26±11</td>
<td>15±14</td>
<td>14±9</td>
<td>17±11</td>
<td>21±12</td>
<td>23±15</td>
<td>31±13</td>
<td>27±12</td>
</tr>
</tbody>
</table>

*Significant differences in EMG activity among exercises (p < 0.001)

1Significantly greater EMG activity (p < 0.05) than BB®1
2Significantly greater EMG activity (p < 0.05) than BB®2
3Significantly greater EMG activity (p < 0.05) than BB®3
4Significantly greater EMG activity (p < 0.05) than BB®4
5Significantly greater EMG activity (p < 0.05) than BB®5
6Significantly greater EMG activity (p < 0.05) than BB®6
7Significantly greater EMG activity (p < 0.05) than BB®7

similar among the remaining exercises. Infraspinatus activity was greatest in BB®2, BB®3, and BB®6 and least in BB®1, BB®5, and BB®7.
compared to the BB®C because the BB®P is heavier and longer than the BB®C and may be more difficult to handle was partially supported by the data. Although muscle activity in the BB®P was higher compared to the BB®C in most exercise and muscle comparisons, significant differences in muscle activity only occurred in 33% of the exercise and muscle comparisons (Table 3). The anterior deltoid, posterior deltoid, sternal pectoralis major, serratus anterior, and infraspinatus demonstrated significantly greater activity during the BB®P compared to BB®C in roughly 50% of the exercises tested, while the latissimus dorsi, upper trapezius, and lower trapezius exhibited significantly greater activity in the BB®P compared to the BB®C in less than 30% of the exercises tested. These data demonstrate that the BB®P was more effective than the BB®C in the overall ability to affect glenohumeral and scapular muscle activity during BB® exercises. A clinical implication is that since muscle activity (and presumably force) was lower when performing the BB®C compared with the BB®P, the BB®C may be employed first in rotator cuff rehabilitation and rehabilitation of other conditions demanding stability, and then progressed to the BB®P.

Very few interactions were found between gender and exercise device. BB®4 (Figure 5) and BB®6 (Figure 7) were the only two exercises in which muscle activity between males and females depended upon whether BB®P or BB®C was employed. For males, the BB®P was more effective in infraspinatus activity compared to using the BB®C during BB®4 and BB®6, however this was not shown for females. This implies that when targeting infraspinatus activity in females, it does not matter which BB® device is utilized in the clinic. However for males, the device does make a difference. Therefore, clinically, it may be appropriate to employ the BB®C first and progress to the BB®P. A clinical application for males after rotator cuff repair rehabilitation is that the BB®C may be employed first and progressed to the BB®P, since infraspinatus activity (and presumably force) was less in the BB®C and greater in the BB®P.

The hypothesis that glenohumeral and scapular muscle activity would be significantly different among the seven BB® exercises given that the movement patterns occur in different planes and body positions is supported by the results of this study. (Table 4). To help generalize the comparisons in muscle activity from tables 1-3, 0–20% of a maximum voluntary isometric contraction (MVIC) was considered low muscle activity, 21–40% MVIC was considered moderate muscle activity, 41–60% MVIC was considered high muscle activity and >60% MVIC was considered very high muscle activity, as previously defined.20 From Tables 2-4 it is clear that muscle activity ranged between low activity to high activity while performing the seven BB® exercises. Clinically, the exercises that generated relatively low activity (BB®1 and BB®7) may be more appropriate during the early rehabilitation phases. The exercises that generated relatively moderate activity (BB®2, BB®4, BB®5) to relatively high activity (BB®3, BB®6) may be more appropriate during the mid-to-late rehabilitation phases as the tissues progressively become stronger.

The hypothesis that glenohumeral and scapular muscle activity would be significantly greater using the BB® with two hands compared to performing the same pattern and movement BB® exercise with one hand was not supported by the results. Although BB®4 (Figure 5) and BB®5 (Figure 6) were performed in a similar manner except BB®4 used one hand and BB®5 used two hands, muscle activity was similar between these two exercises in all muscles except the serratus anterior and infraspinatus (Table 4). Compared to the one hand BB®4, the serratus anterior was significantly greater and the infraspinatus was significantly less in the two hand BB®5. A potential clinical application, such as during the early rehabilitation phases after infraspinatus repair, is to start with the two handed BB®5 exercise (low end of moderate muscle activity from the infraspinatus) and eventually progress to the one handed BB®4 exercise (high end of moderate muscle activity from the infraspinatus). BB®5 may also be desirable given its moderately high serratus anterior activity, which is an important muscle to train early during shoulder rehabilitation given its important role as an upward rotator of the scapula during arm elevation.

It is sometimes difficult to compare normalized EMG results among similar studies from the literature because of the different exercises, normalization techniques, and muscles that were assessed. Two studies3, 5 that did exercises similar to BB®3, BB®4, and
BB®5 in the current study, and used similar muscles and EMG normalization techniques as the current study, reported very similar shoulder muscle activity results as in the current study. In contrast, compared to the current study, Parry et al\(^6\) reported higher normalized EMG values for the pectoralis major, deltoïds, and serratus anterior with means and standard deviations between 65-90±22-33% MVIC, but it is unclear if the exercises were performed in a similar manner as in the current study.

The current study assessed eight glenohumeral and scapular muscles and no other authors have assessed more than four muscles, so the current study is the most comprehensive in terms of assessing glenohumeral and scapular musculature. Lister et al\(^4\) assessed muscle activity from the serratus anterior, upper and lower trapezius, Parry et al\(^6\) examined the deltoid, infraspinatus, serratus anterior, and pectoralis major, Moreside et al\(^3\) assessed the latissimus dorsi, anterior deltotoid, pectoralis major, Oliver et al\(^5\) assessed the deltoid, lower and upper trapezius, and infraspinatus, and Arora et al\(^1\) investigated deltotoid activity. The more comprehensive EMG analysis in the current study is important because scapular and glenohumeral muscles work together in unison during arm movements in sport and activity. Employing exercises that recruit all these important muscles synchronously may help enhance performance and minimize injuries.

A clinical application of using the BB\(^*\) in shoulder rehabilitation, such as with individuals with shoulder instability, is that males may be able to employ the BB\(^*\) earlier in rehabilitation compared to females. This is because higher relative muscle activity, and presumably higher muscle force, occurred in females compared to males during the BB\(^*\) exercises. Also, excessive muscle force to the healing tissue is a contraindication in the early phases of rotator cuff rehabilitation. There is only one known study in the literature that assessed the BB\(^*\) during shoulder rehabilitation (shoulder instability) and after 11 physical therapy sessions the patient improved shoulder range of motion, strength, and function.\(^{11}\)

The use of the BB\(^*\) should be considered depending on specific goals and effects on targeted musculature. Clinically, if the goal is to minimize rotator cuff activity from the infraspinatus, such as in the early rehabilitation phases after infraspinatus repair, BB®1 (Figure 2), BB®5 (Figure 6), and BB®7 (Figure 8) may be the most appropriate exercises to start with given they exhibited the lowest infraspinatus activity (at the low end of moderate muscle activity) (Table 4). Moreover, if the training or rehabilitation goal is to maximize scapular muscle activity from the trapezius and serratus anterior musculature, BB®3 (Figure 4) and BB®6 (Figure 7) may be the most appropriate exercises to employ as they both generated high serratus anterior and upper/lower trapezius activity (Table 4). As previously mentioned, the serratus anterior and upper/lower trapezius stabilize the scapula and properly position the scapula on the thorax during arm elevation such as overhead throwing.\(^9,10\) BB®1 (Figure 2) and BB®3 (Figure 4) were most effective for the latissimus dorsi while BB®4 (Figure 5) and BB®5 (Figure 6) were the most effective for the sternal pectoralis major (Table 4). Finally, if the goal is to maximize muscle activity from the anterior deltotoid, posterior deltotoid, and infraspinatus, BB®3 (Figure 4) and BB®6 (Figure 7) were shown to be the most effective (Table 4). The anterior and posterior deltotoid muscles are important prime movers of the glenohumeral joint. The infraspinatus is an important glenohumeral dynamic stabilizer, external rotator, and abductor, that also helps resist anterior and superior humeral head translation by applying the inferoposterior force to the humeral head during arm elevation.\(^21\) The infraspinatus also exhibits high to very high muscle activity during many different overhead throwing activities,\(^{20,22}\) and as it externally rotates the humerus it helps clear the greater tuberosity from under the coracoacromial arch, thus minimizing the risk of subacromial impingement.\(^7,10\)

In shoulder rehabilitation, exercises generally begin with the arm at or near the side and over time the patient's arm is progressively moved into a position of flexion or abduction. One exercise (BB®1) was performed with the arm at the side with 0° abduction (Figure 2). Given BB®1 generally had among the lowest muscle activity in all muscles (except the latissimus dorsi) compared to the other six exercises, it may be a good choice to begin with during the early phases of shoulder rehabilitation. Two of the exercises (BB®4, BB®5) were performed with the shoul-
ders and elbows flexed approximately 45° (Figures 5 and 6). These exercises had greater overall muscle activity than BB*1 so may be appropriate exercises to progress to. Four of the exercises in the current study were performed with shoulder flexed or abducted approximately 90° (BB*2, BB*3, BB*6, and BB*7 (Figures 3, 4, 7, and 8). These exercises, especially BB*3 and BB*6, had the greatest overall glenohumeral and scapular muscle activity. Therefore, these exercises may be appropriate in the later phases of shoulder rehabilitation after tissue healing is near completion.

The most effective exercises in overall glenohumeral and scapular muscle activity were BB*3 (Figure 4) and BB*6 (Figure 7). In contrast to BB*1 (Figure 2), which exhibited the lowest overall muscle activity, BB*3 and BB*6 may be reserved for the later phases of shoulder rehabilitation and training. One interesting difference between BB*3 and BB*6 is that even though upper/lower trapezius, serratus anterior, and infraspinatus activity were similar between BB*3 and BB*6, there was significantly more anterior and posterior deltoid activity in BB*3 compared to BB*6. Another interesting difference is that BB*3 was performed using one hand and BB*6 was performed using two hands.

Limitations
Cross talk should always be considered to be a limitation in EMG studies, especially surface EMG studies. Cross talk was minimized by using standardized electrode positions that have been tested previously. With the electrodes centered over the muscle bellies and the muscles in the current study being relatively large, cross talk was minimized in the current study.

Another limitation from the current study is being able to interpret how the EMG signal is related to muscle force. Caution should be used when correlating muscle activity with muscle force. Linear, quasi-linear (near linear), and non-linear correlations have been reported in the literature between EMG amplitude and muscle force during muscle actions. Generally, the relationship between EMG amplitude and muscle force is most linear during isometric muscle actions or during activities when muscle length is not changing rapidly during concentric and eccentric muscle actions, which occurred while performing the BB* exercises in the current study.

Given the quasi-static nature of performing the BB*, and given that muscle force increases somewhat linearly with muscle activity during static or quasi-static muscle actions, the authors assume that as muscle activity increased during the BB* that muscle force also increased, at least to some degree.

It is still unknown how vibration type training like training with the BB* enhances performance and the rehabilitation process and further research is needed. The 4.5 Hz from the BB* is quite different than the 15-50Hz used during whole body vibration studies. It is also currently unknown if some of the same benefits observed in vibration training also occurs with BB* training, such as enhanced neuromuscular performance, increased activation of prime movers, better synergist synchronization, and enhanced proprioception.

Finally, the ability to generalize the results from this study to individuals with shoulder dysfunction is limited, and further research is needed. Nearly all of the studies from the literature used healthy subjects and there are no known BB* studies that used a cohort of patients with shoulder dysfunction. The only known BB* study that utilized subjects with shoulder pathology was a case report describing an 18 year old male. Because males and females as well as different BB* devices have never been compared before, the current study provides an initial understanding of shoulder muscle recruitment patterns in normal males and females while performing a variety of exercises using the BB*P and BB*C. Further research should be conducted with individuals participating in a shoulder rehabilitation program.

CONCLUSIONS
When performing BB* exercises glenohumeral and scapular muscle activity was often greater in females compared to males and often greater in exercises using the BB*P compared to using the BB*C. This suggests that it may be appropriate to employ BB* exercises during shoulder rehabilitation earlier for males compared to females given the relative work intensity was less in males compared to females. It may also be appropriate to employ BB* exercises earlier using the BB*C compared to the BB*P given the relative work intensity found related to the BB*C compared to the BB*P.
When performing a BB® exercise using two hands compared to the same arm motion using one hand, anterior deltoid and serratus anterior activity was greater with two hands while infraspinatus activity was greater with one hand. The knowledge of difference in muscle recruitment patterns using varying techniques can be used during different types and phases of rehabilitation.

Performing BB® exercises, such as BB®1, with the arm at the side may be most appropriate early during shoulder rehabilitation due to its relatively low muscle activity, then with shoulders flexed 45°, and finally progressing to shoulders flexed 90°. The two BB® exercises that were most effective in overall glenohumeral and scapular muscle activity were exercises performed with 1) one hand with 90° shoulder abduction and superoinferior oscillations, and 2) two hands with 90° shoulder flexion and superoinferior oscillations. This implies that performing the BB® with a horizontal special orientation and using an up and down motion may be most effective in shoulder muscle recruitment patterns.

REFERENCES
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ABSTRACT

Background: Stationary equipment devices are often used to improve fitness. The ElliptiGO® was recently developed that blends the elements of an elliptical trainer and bicycle, allowing reciprocal lower limb pedaling in an upright position. However, it is unknown whether the muscle activity used for the ElliptiGO® is similar to walking or cycling. To date, there is no information comparing muscle activity for exercise on the treadmill, stationary upright and recumbent bikes, and the ElliptiGO®.

Purpose/Hypothesis: The purpose of this study was to assess trunk and lower extremity muscle activity among treadmill walking, cycling (recumbent and upright) and the ElliptiGO® cycling. It was hypothesized that the ElliptiGO® and treadmill would elicit similar electromyographic muscle activity responses compared to the stationary bike and recumbent bike during an exercise session.

Study Design: Cohort, repeated measures

Methods: Twelve recreationally active volunteers participated in the study and were assigned a random order of exercise for each of the four devices (ElliptiGO®, stationary upright cycle ergometer, recumbent ergometer, and a treadmill). Two-dimensional video was used to monitor the start and stop of exercise and surface electromyography (SEMG) were used to assess muscle activity during two minutes of cycling or treadmill walking at 40-50% heart rate reserve (HRR). Eight muscles on the dominant limb were used for analysis: gluteus maximus (Gmax), gluteus medius (Gmed), biceps femoris (BF), lateral head of the gastrocnemius (LG), tibialis anterior (TA), rectus femoris (RF). Two trunk muscles were assessed on the same side; lumbar erector spinae at L3-4 level (LES) and rectus abdominus (RA). Maximal voluntary isometric contractions (MVIC) were determined for each muscle and SEMG data were expressed as %MVIC in order to normalize outputs.

Results: The %MVIC for RF during ElliptiGO® cycling was higher than recumbent cycling. The LG muscle activity was highest during upright cycling. The TA was higher during walking compared to recumbent cycling and ElliptiGO® cycling. No differences were found among the the LES and remaining lower limb musculature across devices.

Conclusion: ElliptiGO® cycling was found to elicit sufficient muscle activity to provide a strengthening stimulus for the RF muscle. The LES, RA, Gmax, Gmed, and BF activity were similar across all devices and ranged from low to moderate strength levels of muscle activation. The information gained from this study may assist clinicians in developing low to moderate strengthening exercise protocols when using these four devices.

Level of evidence: 3

Keywords: Cycling, electromyography, elliptical, ergometers, lower extremity, muscle activity, treadmill

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INTRODUCTION
It is well known that regular physical activity can reduce the risk for cardiovascular disease, Type 2 diabetes, cancer, stroke, obesity, and many other non-communicable diseases. In order to improve health and quality of life, it has been recommended that adults should participate in at least 150 minutes per week of moderate-intensity physical activity. Running is one of the most popular methods of physical activity which offers many health benefits. However, running is not tolerated by everyone and also has a high incidence of lower extremity injuries. There is no one particular cause for running injuries, and are more likely related to several variables such as training intensity, frequency, and distance as well as the repetitive impact loading on the joints.

Health care professionals commonly prescribe stationary cycling or elliptical training as a low-impact alternative to walking or running in order to reduce stress on the hip or knee joints. These forms of exercise could benefit runners who have lower extremity musculoskeletal injuries since elliptical training has been found to have reduced lower limb loading rates compared to walking. Cross training such as a combination of cycling and running has been shown to be an effective way to maintain aerobic capacity for runners. White et al found that collegiate female distance runners who substituted 50% of their running time for cycling had similar aerobic fitness compared to females who ran 100% of their time during the cross country season.

Cycling or elliptical training has been found to facilitate lower limb coordination or improve reciprocal muscle activity. Researchers have studied the use of cycle ergometry to improve muscle strength among healthy older women, people with multiple sclerosis, and individuals who were post-stroke. These authors found improvements in lower extremity muscle strength, power, and postural control. Macaluso et al reported increased muscle strength and power among older women at 40% of a 2-repetition maximum and at 80% of a 2-repetition maximum using cycling training. Elliptical exercise has also been found to result in higher quadriceps and hamstring loading compared to walking as well as lower vertical reaction forces during elliptical cycling compared to walking. It appears that cycling and elliptical training are effective exercise modes for muscle strengthening for individuals who prefer these devices instead of running or walking.

Many researchers have analyzed muscle activity during upright cycling, elliptical cycling, recumbent cycling, and treadmill walking; however few have compared a combination of these exercise devices and the methodology has varied across studies. Results of research that has assessed muscle activity among various equipment devices have been difficult to compare as methodologies and equipment design vary widely among the literature. For example, the gastrocnemius and gluteus maximus have been found to be less active using a Precor EFX 576i (OH,USA) elliptical trainer compared to treadmill walking whereas others who studied five elliptical models (SportsArt Fitness E870, Life Fitness X7, Octane Fitness Pro4500, True Fitness Technology TSXa) reported higher gluteus maximus muscle activity compared to walking beyond over ten meters. Burnfield et al allowed the participants to self-select a comfortable speed for both treadmill and elliptical training, as compared to the research by Sozen who established the exercise intensity at 65% of maximum heart rate which may have resulted in muscle activity differences. An understanding of muscle activity recruitment among exercises devices would enable physical therapists to make better evidence practice decisions for their patients.

Recently, ElliptiGO® (ElliptiGO® Inc., Solana Beach, CA) was developed to resemble a blend of elliptical and running exercise. This device is built on two wheels and can be placed on an indoor trainer or can stand alone and be ridden outdoors. The bike design combines cycling and elliptical pedaling so that the cycling is performed standing up with the lower legs aligned vertically on two platform pedals. The manufacturer contends that the foot platforms are designed to simulate a running-like experience since the platforms are positioned closer together and allow for longer stride length compared to elliptical machines. To the authors’ knowledge, no research has been performed comparing muscle activity patterns while using the ElliptiGO® to other modes of exercise such as treadmill walking or cycling. Thus, the purpose of this study was to assess trunk and lower extremity muscle activity among treadmill...
walking, cycling (recumbent and upright) and the ElliptiGO® cycling. It was hypothesized that the ElliptiGO® and treadmill would be more similar in muscle activity compared to the stationary bike and recumbent bike.

**METHODS**

Twelve recreationally active, healthy volunteers participated in the study. Recreationally active was defined as someone who participated in recreational activities for at least 30 minutes per day. The sample size was determined based on a study with similar independent variables where ten subjects were studied using elliptical training, stationary cycling, treadmill walking and over ground walking. Subjects were recruited using a sample of convenience from the university campus and the study involved a single-session research design. Exclusion criteria consisted of anyone diagnosed with musculoskeletal, cardiovascular, vestibular, visual, neurological, or balance disorders, or have a history musculoskeletal injury requiring medical treatment in the past year. The protocol was approved by the Institutional Review Board, project number 607. An informed consent was provided to all subjects explaining the risks and benefits of the study.

**Instrumentation**

Muscle activity data was collected using telemetry transmitter (8-channel, 12-bit analog-digital converter, Noraxon Myosystem 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 trunk, three meters anterior to the subject for a sagittal plane recording during the exercise testing. A transmitter belt unit powered by a 9V battery was worn to collect surface electromyography (SEMG) signals. The raw SEMG data were sampled at 1000Hz for each of the eight muscles on the dominant limb and converted to a mean amplitude and used for SEMG analysis: gluteus maximus (Gmax), gluteus medius (Gmed), lumbar erector spinae (LES), biceps femoris (BF), lateral head of the gastrocnemius (LG), tibialis anterior (TA), rectus femoris (RF), and rectus abdominus (RA). The amplifier bandwidth frequency ranged from 10Hz highpass to 500 Hz lowpass and common mode rejection = 85dB. 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 onset of each of the eight muscle contractions during the four exercise modes were marked by when the start of the motion as noted on the video recording and when the muscle SEMG amplitude was 10 μV of baseline. The raw SEMG signals were processed using a full-wave rectification and root-mean-square algorithm at a time constant of 300 milliseconds.

**Procedures**

Anthropometric measurements were taken, including height and weight using a standard scale, (Detecto, Webb City, MO). Silver-silver chloride snap single surface pre-gelled electrodes (Noraxon USA, Inc., Scottsdale, AZ) were placed in a bipolar configuration on the skin of the dominant leg and torso of the same side of dominant limb. Leg dominance was defined as the preferred limb for kicking a ball. Subjects 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 prior to electrode placement. The ground lead was placed on the subject’s patellar tuberosity contralateral to the subject’s dominant limb. Each subsequent lead was positioned on the subject’s dominant limb side and parallel to the muscle fibers and described in detail in Table 1.

Prior to the start of data collection, subjects participated in a warm-up session consisting of self-selected pace of walking for five minutes. Three maximal voluntary isometric contractions (MVIC) were performed in standard manual muscle test positions for each subject for the eight muscles analyzed. Each test for the MVIC was held for five seconds, followed by a three second rest 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, and manual resistance applied approximately 40 degrees from full knee extension. The subject was positioned in prone for the 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 gluteus medius muscle was assessed in a sidelying position, with the hip in neutral rotation and slightly extended with minimal resistance applied to the distal lower leg as the hip actively moved into abduction. The lumbar erector spinae was tested with the subject in a prone position and trunk off the edge of the table at the level of the anterior superior iliac spine. A second investigator stabilized the lower extremity just above the ankle as the subject extended the lumbar spine to neutral and resistance was applied to the posterior scapulae. The biceps femoris was tested in prone position with the knee flexed to 45 degrees and lower leg in external rotation. The lateral gastrocnemius was tested in prone position with the foot over the edge of the table and manual resistance was applied to the plantar aspect of the foot. The test position for the tibialis anterior was in sitting with knee flexed to 90 degrees and manual resistance applied against the medial and dorsal aspect of the foot. The rectus abdominis was tested in supine and hook-lying position. The subject was instructed to place arms across chest and perform a partial curl-up (flexed position) while the investigator applied matched resistance bilaterally shoulders to prevent the motion. The average SEMG amplitudes collected during the exercise conditions were later normalized to the highest MIVC value of the three MVIC trials obtained during the manual muscle tests, and expressed as percentage of MIVC, (%MVIC). Following MIVC data collection, participants rested five minutes prior to additional data collection.

The subjects were given verbal instructions and demonstrations for each exercise. Subjects were also given the opportunity to acclimate to the exercise modes by walking and cycling for approximately two minutes prior to data collection. Participants were assigned a random order for each of the four exercise devices; ElliptiGO® Model 3C (ElliptiGO Inc., Solana Beach, CA), stationary upright friction-braked Monark 828E cycle ergometer (Monark Exercise AB, Vansbro, Sweden), recumbent ergometer (Model T4/TRS 4000) (NuStep Inc., Ann Arbor, MI), and a single-belted treadmill (Trackmaster TMX58, Full Vision Inc., Newton, KS).

The rear wheel of the ElliptiGO® was placed on a stationary trainer. The subjects were instructed to maintain an upright posture and both feet in contact with the pedals during cycling (Figure 1). The feet were positioned in the center of the pedal with each of the subject’s legs perpendicular to the ground. The Monark cycle ergometer seat height was determined by measuring 95% of the distance from the right greater trochanter to the floor with the subject in standing position. The handlebars were adjusted for comfort and then remained constant throughout the cycling bout. The participant was instructed to remain seated during the test. The seat and distance from the pedal for each participant

Table 1. Electrode placement for the trunk and lower extremity musculature.

<table>
<thead>
<tr>
<th>Trunk and Lower Extremity Muscles</th>
<th>Electrode Placement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gluteus Maximus</td>
<td>3 cm inferior and medial to a line drawn between posterior superior iliac spine and posterior greater trochanter</td>
</tr>
<tr>
<td>Anterior portion of Gluteus Medius</td>
<td>3 cm inferior to the iliac crest</td>
</tr>
<tr>
<td>Biceps Femoris</td>
<td>Midway between the ischial tuberosity and the crease of the popliteal fossa</td>
</tr>
<tr>
<td>Lateral Gastrocnemius</td>
<td>2 cm lateral from midline, just distal to knee</td>
</tr>
<tr>
<td>Tibialis Anterior</td>
<td>1/4 to 1/3 of the distance between knee and ankle, just lateral to shaft of tibia</td>
</tr>
<tr>
<td>Rectus Femoris</td>
<td>Along the longitudinal fibers midway between the anterior superior iliac spine and base of patella</td>
</tr>
<tr>
<td>Upper Rectus Abdominus</td>
<td>3 cm lateral from midline, and at the midpoint between umbilicus and xiphoid process</td>
</tr>
<tr>
<td>Lumbar Erector Spinae (L3-L4)</td>
<td>2 cm lateral from spinous process between L3 and L4 in a vertical direction</td>
</tr>
</tbody>
</table>
was set so that the knees were slightly bent when the legs were maximally extended. Handlebars were adjusted by placing the arm in neutral alignment allowing approximately 60 degrees of elbow flexion. The forefoot was placed on the pedal without straps or clips. Subjects were instructed to remain on their seat and have their hands in contact with handlebars during the cycling bout. (Figure 2)

Subjects were asked to walk on the treadmill using a self-selected gait speed. The treadmill was set at 0° incline. They were also instructed to maintain free arm swing without holding onto the rails. (Figure 3)

Each subject was fitted to the recumbent bike using a goniometer so that the amount of knee flexion was approximately 15° to 20° of knee flexion during the upstroke and 0° of knee flexion during the down stroke. Subjects were instructed to hold onto handlebars and feet in pedals throughout the cycling duration. (Figure 4)

The exercise duration and intensity were consistent for each of the four exercise devices. Exercise
duration was five minutes, (two minutes of acclimation, two minutes of data collection at 40-50% heart rate reserve [HRR], and one minute of cool down). The exercise intensity was determined by calculating maximal heart rate using the Karvonen formula (220-age) and then determining 40-50% of estimated HRR using maximal heart rate. The exercise intensity was determined by calculating maximal heart rate using the Karvonen formula (220-age) and then determining 40-50% of estimated HRR using maximal heart rate. The exercise intensity was determined by calculating maximal heart rate using the Karvonen formula (220-age) and then determining 40-50% of estimated HRR using maximal heart rate.37 Heart rate was recorded using a chest heart rate monitor (Polar heart rate, Polar Electro Inc., Lake Success, NY) during each exercise mode. Subjects were also asked to rate the perceived exertion (RPE) at the completion of each exercise trial. The subjects were given verbal and written instructions on Borg’s 10-point RPE scale before each trial. A copy of the RPE scale was kept in full view of the subjects during each trial.

The upright cycle ergometer cadence was set at 60 revolutions per minute. The subject was able to monitor the cadence by the digital monitor display on the ergometer. In order to maintain the appropriate exercise intensity for the upright and recumbent bikes, resistance was either added or removed by manipulating the dial tension. ElliptiGO® cycling intensity was changed by either increasing or decreasing the rate of pedal motion. The treadmill speed was adjusted by the investigator from the treadmill control panel throughout the walking bout based on the participant’s heart rate response.

**Statistical Analysis**

Descriptive statistics are reported as means ± standard deviations for demographic data and muscle activity. Shapiro-Wilk’s W-test was applied to examine normality in the distribution of data. The singular peak maximal voluntary isometric contractions (MVIC) 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 and ANOVAs were calculated using SPSS version 21.0 (SPSS, Inc, Chicago, IL) software. The normalized SEMG values were analyzed using separate one-way analyses of variance. Post-hoc comparisons of the means of interest were conducted using the Bonferroni procedure and set at \( p < 0.05 \).

**RESULTS**

Twelve participants (six males, six females) with a mean age of 32.42 ± 8.3 years, height 168.75 ± 7.0 cm, and mass 77.65 ± 14.4 kg were involved in the study. The means and standard deviations of the SEMG results across the eight muscles are presented in Table 1. The mean SEMG data for the lumbar erector spinae (LES) muscles ranged from 20%MVIC for the recumbent cycling to 44%MVIC on the treadmill. There were no main effect differences among the equipment devices for muscle activity for RA (\( p = .331 \)), lumbar (\( p = .164 \)), Gmax (\( p = .255 \)), Gmed (\( p = .623 \)) or BF (\( p = .227 \)). Mean SEMG RA muscle activity ranged from 41%MVIC during recumbent cycling to 58%MVIC on the treadmill. Gluteus maximus and medius SEMG mean activity ranged within 15%MVIC to 26%MVIC across the four exercise devices. Biceps femoris average SEMG activity ranged from 18%MVIC during recumbent cycling to 37%MVIC with treadmill walking.

The %MVIC for RF during ElliptiGO® cycling was significantly higher (46% MVIC) compared to recumbent cycling, (16% MVIC), (\( p = .001 \)). The LG was highest during upright cycling (71% MVIC) and significantly higher than recumbent cycling (\( p = .001 \)) and ElliptiGO® cycling (\( p = .03 \)). Treadmill walking (58% MVIC) also resulted in higher LG activity compared to recumbent cycling, 33% MVIC.

**Figure 4.** Recumbent cycling at 40% to 50% of heart rate reserve.
The greatest tibialis anterior activity was found during treadmill walking (43% MVIC) compared to recumbent cycling (19% MVIC) ($p = .02$). The greatest lateral gastrocnemius activity was found during upright cycling compared to recumbent cycling ($p = .03$). The tibialis anterior activity was higher during treadmill walking compared to recumbent cycling ($p = .002$).

**DISCUSSION**

The purpose of the current study was to compare trunk and lower extremity muscle activity during the use of four stationary exercise devices. The results partially supported the hypothesis that the treadmill and ElliptiGO® would elicit similar muscle activity compared to the recumbent and upright stationary cycling. As hypothesized, the lateral gastrocnemius activity was different between treadmill walking and ElliptiGO® cycling, however, the lateral gastrocnemius muscle activity was similar during upright stationary cycling. Comparable SEMG activity was found among all four devices for lumbar erector spinae, biceps femoris, rectus abdominus, gluteus medius, and gluteus maximus muscles. Contrary to the stated hypothesis, the treadmill elicited higher tibialis anterior muscle activity compared to the ElliptiGO®.

The stationary upright, recumbent, or elliptical devices vary in sitting and pedaling positions, which may explain some of the differences seen in SEMG outputs. For example, these exercise modes differ with the seat-to-crank set frame alignment, which alters trunk alignment and amount of bodyweight supported by limbs. The standard bike seat is positioned above the crank set compared to the recumbent bike which has the seat at the same level and in line with the crank set. The seat also allows the back of recumbent cyclist to be supported and reclined back compared to the standard bike in which the cyclist must lean more forward. Despite these differences in frame and saddle heights, the trunk muscles (rectus abdominus and lumbar erector spinae), hip muscles (biceps femoris, gluteus maximus, gluteus

<table>
<thead>
<tr>
<th></th>
<th>ElliptiGO®</th>
<th>Recumbent</th>
<th>Upright</th>
<th>Treadmill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectus abdominus</td>
<td>50.7±26.72</td>
<td>41.8±15.33</td>
<td>55.0±26.60</td>
<td>58.2±20.63</td>
</tr>
<tr>
<td>Lumbar ES</td>
<td>36.3±25.61</td>
<td>20.2±17.04</td>
<td>36.8±33.13</td>
<td>44.7±28.20</td>
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<tr>
<td>Biceps Femoris</td>
<td>26.8±24.91</td>
<td>18.3±13.74</td>
<td>32.9±18.34</td>
<td>37.4±32.08</td>
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<tr>
<td>Rectus Femoris</td>
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<td>15.8±6.64*</td>
<td>30.1±20.00</td>
<td>29.9±15.59</td>
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<tr>
<td>Gluteus Maximus</td>
<td>26.5±17.13</td>
<td>15.4±7.66</td>
<td>17.9±17.42</td>
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<td>Gluteus Medius</td>
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<td>17.1±19.81</td>
<td>24.4±25.01</td>
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<tr>
<td>Lateral Gastroc</td>
<td>47.9±25.72†</td>
<td>33.3±9.61†</td>
<td>71.2±13.68†</td>
<td>57.7±23.50§</td>
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<tr>
<td>Tibialis Anterior</td>
<td>19.3±10.94§</td>
<td>19.3±13.53§</td>
<td>30.2±11.12</td>
<td>43.3±22.51§</td>
</tr>
</tbody>
</table>

Data expressed as percentage of maximum voluntary isometric contraction, (%MVIC).

* For rectus femoris muscle, statistically significantly higher %MVIC for ElliptiGO® compared to recumbent cycling, ($p=.001$).

† For lateral gastrocnemius muscle, statistically significantly higher %MVIC for upright cycling compared to recumbent and ElliptiGO® cycling, ($p=.03$).

‡ For lateral gastrocnemius muscle, statistically significantly higher %MVIC for treadmill walking compared to recumbent cycling, ($p=.02$).

§ For tibialis anterior muscle, statistically significantly higher %MVIC for treadmill walking compared to recumbent and ElliptiGO® cycling, ($p=.002$).
medius) elicited similar muscle activity across the four equipment devices examined in the current study. Other researchers have also found that upper limb and lower limb muscle activity to be highly correlated between the recumbent bike and BWS treadmill walking when walking speed and cycling were matched for similar exercise intensity.25

Trunk Muscles
The rectus abdominus muscle mean SEMG value among the four equipment devices was 51% MVIC. This muscle activity value falls within the activation level needed for strengthening the abdominal muscles.39,40 While the rectus abdominus activity was not assessed in a study by Anderson et al, these authors reported 40% to 60% is an adequate range for muscle strengthening.41 The only exercise that resulted in sufficient muscle activity for lumbar erector spinae strengthening was treadmill walking, (45% MVIC). In contrast, if a low exercise intensity is the focus during the early phase of rehabilitation for lumbar erector spinae muscles, then the ElliptiGO®, upright and recumbent bikes would be appropriate since the muscle activity values fell below the strengthening intensity level.

Hip Muscles
The results of the current study indicate that the ElliptiGO® cycling produced 46% MVIC activity for the rectus femoris muscle which was significantly higher than recumbent biking, (16% MVIC). The higher rectus femoris activity may be because of greater lower extremity weight bearing since the subject is required to perform cycling motion in a standing position on the ElliptiGO® compared to cycling in a recumbent sitting position. In addition, 46% MVIC has been found to be a sufficient level to elicit neuromuscular adaptation needed for strengthening.41 This may be advantageous for runners to maintain the hip flexor and knee extensor muscles using a simulated running gait pattern via the ElliptiGO®. Since elliptical cycling has been found to elicit smaller joint forces compared to walking,8 we can only speculate that limb loading may also be reduced using the ElliptiGO® since it offers a similar pedal motion as the elliptical device.

Treadmill walking and upright cycling both elicited 30% MVIC for the rectus femoris muscle. While treadmill walking requires more weight bearing load compared to upright cycling, there is no foot resistance while waking to advance the limb forward, which may explain the lower muscle activity. In contrast, ElliptiGO® cycling involves overcoming pedal resistance in order to propel the lower limb forward via hip flexion and knee extension motions resulting in higher rectus femoris activity. Lopes et al reported peak mean SEMG values when comparing upright and recumbent cycling at 80rpm and a work rate of 100W.27 These authors found upright and recumbent cycling elicited 23% MVIC and 20% MVIC RF activity, respectively. The current study found a slightly higher value (30% MVIC) for the upright bike and slightly lower EMG activity (16% MVIC) for the recumbent cycle.

The gluteus maximus and gluteus medius muscles elicited values below the strengthening stimulus across all four exercise devices. While exercise devices produced low %MVIC levels, these muscles have been found to serve an important role during walking and cycling. The gluteus medius muscle has been found to be a pelvis stabilizer by limiting the amount of forward rotation during walking.42 During cycling, the gluteus maximus and rectus femoris work together as agonist and antagonist to coordinate muscle activity at the hip.43 Other muscle patterns such as the biceps femoris and plantarflexors (gastrocnemius and soleus) have been found to be synchronized together at the end of the extension phase of cycling and during the extension-to-flexion transition phase.44 Despite these coordinated muscle patterns, the biceps femoris was also found to be below the level for strengthening stimulus for all four exercise devices. Lopes et al also found similar muscle activity values for the semitendinosus muscle during upright and recumbent cycling.27

Lower limb Muscles
The lateral gastrocnemius muscle ranged from 33% MVIC to 71% MVIC. The treadmill elicited 58% MVIC and the upright bike was 71% MVIC which indicates that these exercise modes could be used for sufficient stimulus for calf strengthening. Upright cycling produced the highest lateral gastrocnemius activity, particularly compared to ElliptiGO® and recumbent biking. The likely explanation for the differences between the current study and Sozen24 is that different exercise intensity and devices were
used. Sozen used the Precor EFX 576i, (OH, USA) elliptical at a 65% maximum heart rate intensity compared to the present study which selected ElliptiGO® cycling at 40-50% maximum heart rate intensity. The high SEMG value may also be explained by the position of the ankle. During this study, the participant’s forefoot was placed on the pedal, which allowed for ankle motion. Upright cycling has been found to influence lateral gastrocnemius activity when the ankle is in a dorsiflexed position. Cannon et al reported that the lateral gastrocnemius activity increases during dorsiflexion in order to generate knee flexion. The gastrocnemius has been found to function as a knee flexor during cycling. While the current study did not monitor the amount of ankle motion occurring during the pedal stroke, the participant’s ankle was able to move through dorsiflexion and plantarflexion as the pedal moved in the upstroke and down stroke patterns. Lopes found higher medial gastrocnemius activity (34%) for both upright and recumbent cycling compared to rectus femoris, tibialis anterior, and semitendinosus. The medial gastrocnemius muscle has been found to be active during pedaling motion. The current study did not assess medial gastrocnemius activity, however, did find that the lateral gastrocnemius was most active during upright cycling and less active during recumbent cycling. During upright cycling, the plantarflexors have been found to be active during a portion of the upstroke as well as throughout the entire downstroke phase of cycling compared to the dorsiflexor activity only during the initial phase of the upstroke which may also explain higher gastrocnemius muscle compared to tibialis anterior activity reported in the present study.

Overall, the tibialis anterior elicited low strengthening values, (19% MVIC and 30% MVIC) during recumbent and upright biking respectively which was similar to values reported during recumbent biking in a separate study. The ElliptiGO® involves having the participant stand with the feet placed onto pedal platforms. This type of setup limits the amount of ankle dorsiflexion and plantarflexion motions because the feet do not leave the platform. The cycling motion is also different in that the feet move in an elliptical pattern compared to a circular pattern used by cyclists when on the upright or recumbent ergometers. Treadmill walking involves dorsiflexion and plantarflexion of the ankle whereas the other exercise modes have the feet fixed on platforms, which limit ankle motion. This may explain why the tibialis anterior and lateral gastrocnemius SEMG values were higher during treadmill walking compared to ElliptiGO® and recumbent cycling in which the feet were fixed to platform pedals.

Limitations and Suggestions for Future Research
A significant limitation to the current study was the use of stationary setup for the ElliptiGO® limiting its functional utility as a mobile device. Likewise, upright and recumbent bicycling conditions were stationary and walking was performed on a treadmill. This makes the muscle activity gathered from surface electromyography difficult to compare to the ElliptiGO® while moving on the road, cycling on the road, or over ground running. Future studies should include over ground running and road cycling to assess differences in muscle activity because of decreased stability as compared to stationary trainers or treadmills. While the exercise intensity was maintained between 40% and 50% HRR during use of each of the four exercise devices, the upright bike was the only device that displayed a digital workload and cadence. Thus, while the exercise intensity was based on heart rate, there may have been speed discrepancies during the two minute data collection capture among the exercise devices. Kinematic information was also not assessed to determine actual hip, knee, and ankle joint angles. It is unknown how these exercise devices may affect other populations such as unfit or individuals with musculoskeletal injuries since the subjects recruited were recreationally active, healthy, and free of musculoskeletal injuries in the past year. In addition, the muscles chosen were superficial and limited to eight because of the electromyography system. Cross-talk with the use of SEMG electrodes from adjacent muscles is always a concern in any SEMG study, even with most rigorous methods and electrode placement. It has been suggested that using a standardized method for SEMG placement improves the recordings at each of the muscle sites. The current investigation used standardized electrode placement for each of the muscles assessed in order to decrease potential for cross-talk.
CONCLUSIONS

The ElliptiGO® cycling condition elicited sufficient SEMG activity for a stimulus for strengthening of the rectus femoris muscle, which may serve as an alternative means for muscle training without the joint loading incurred with walking or jogging. While joint loading forces were not assessed in this study, others have found that ergometer cycling and elliptical training result in smaller lower limb joint loads compared to walking. Many of the other muscles such as lumbar erector spinae, rectus abdominus gluteus maximus, gluteus medius, and biceps femoris were similar in muscle activity across the four exercise devices, providing low to moderate strengthening stimuli. Comparable trunk, gluteal, and hamstring muscle SEMG activities suggest that cross training using the equipment devices at 40% to 50% HRR may be a substitute for low-impact exercise. This was the first study to examine muscle activity while using the ElliptiGO®, recumbent and upright bikes, and treadmill walking. The muscle activity information gained from this study may assist clinicians in developing low to moderate strengthening stimuli for various muscles when using the stationary upright and recumbent bikes, treadmill, or the ElliptiGO®.

REFERENCES


ABSTRACT

Background: The single leg squat (SLS) is a functional task used by practitioners to evaluate and treat multiple pathologies of the lower extremity. Variations of the SLS may have different neuromuscular and biomechanical demands. The effect of altering the non-stance leg position during the SLS on trunk, pelvic, and lower extremity mechanics has not been reported.

Purpose: The purpose of this study was to compare trunk, pelvic, hip, knee, and ankle kinematics and hip, knee, and ankle kinetics of three variations of the SLS using different non-stance leg positions: SLS-Front, SLS-Middle, and SLS-Back.

Methods: Sixteen healthy women performed the three SLS tasks while data were collected using a motion capture system and force plates. Joint mechanics in the sagittal, frontal, and transverse planes were compared for the SLS tasks using a separate repeated-measures analysis of variance (ANOVA) for each variable at two analysis points: peak knee flexion (PKF) and 60° of knee flexion (60KF).

Results: Different non-stance leg positions during the SLS resulted in distinct movement patterns and moments at the trunk, pelvis, and lower extremity. At PKF, SLS-Back exhibited the greatest kinematic differences ($p < 0.05$) from SLS-Front and SLS-Middle with greater ipsilateral trunk flexion, pelvic anterior tilt and drop, hip flexion and adduction, and external rotation as well as less knee flexion and abduction. SLS-Back also showed the greatest kinetic differences ($p < 0.05$) from SLS-Front and SLS-Middle with greater hip external rotator moment and knee extensor moment as well as less hip extensor moment and knee adductor moment at PKF. At 60KF, the findings were similar except at the knee.

Conclusion: The mechanics of the trunk, pelvis, and lower extremity during the SLS were affected by the position of the non-stance leg in healthy females. Practitioners can use these findings to distinguish between SLS variations and to select the appropriate SLS for assessment and rehabilitation.

Level of Evidence: 3

Key Words: Females, kinematics, kinetics, lower extremity, single limb squat

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INTRODUCTION
An estimated 11,000 persons are treated in emergency departments for injuries related to sports, recreation, and exercise activities each day. Furthermore, non-contact lower extremity injuries comprise the majority of the reported incidents. Although the etiologies of many non-contact lower extremity injuries are likely multifactorial, atypical movement patterns and poor neuromuscular control are likely contributors. Identifying and addressing these modifiable factors may reduce the risk of lower extremity injuries.

Functional screening is one strategy used to identify risk factors for lower extremity injuries. It uses dynamic tasks to assess balance, stability, coordinated movement quality, and dynamic alignment throughout the body. A common movement task used for assessment and intervention by clinicians is the single leg squat (SLS). The SLS can be used to examine lower extremity alignment and may be helpful in identifying faulty movement patterns of the trunk, pelvis, and lower extremity. Prior studies examining the SLS have demonstrated that there are biomechanical differences between healthy individuals and those with lower extremity injuries, such as patellofemoral pain (PFP), anterior cruciate ligament (ACL) injuries, and hip chondropathy. For example, Nakagawa et al. found that individuals with PFP performed the SLS with greater ipsilateral trunk lean, contralateral pelvic drop, hip adduction, and knee abduction than those without PFP.

The SLS is performed in a variety of ways in clinical, field, and research settings. Generally, participants are instructed to stand on one leg, squat down as far as possible or to an approximate degree of knee flexion, and return to the initial position. The position of the non-stance leg is often not specified. Altering the non-stance leg position during the SLS may tax the neuromuscular system differently and result in different movement patterns. It is unknown how changing the non-stance leg position during the SLS influences the mechanics of the trunk, pelvis, and lower extremity. A better understanding of how the position of the non-stance leg affects trunk, pelvic, and stance leg mechanics during the SLS may help clinicians modify the SLS to best match their desired task demands.

The purpose of this study was to compare trunk, pelvic, hip, knee, and ankle kinematics and hip, knee, and ankle kinetics of three variations of the SLS using different non-stance leg positions. It was hypothesized that altering the position of the non-stance leg during the SLS would result in different kinematics and kinetics of the trunk, pelvis, and stance lower extremity.

METHODS
This study used a within-subjects, repeated-measures design in a laboratory setting to examine how changing the position of the non-stance leg affects how the SLS is performed. Trunk, pelvic, and lower extremity kinematics and kinetics in the sagittal, frontal, and transverse planes of three common variations of the SLS were examined. The position of the non-stance leg differed between the three SLS tasks. Data were recorded using a 3-dimensional motion capture system and force plates while the participant performed five trials of each of the SLS tasks.

Subjects
Sixteen healthy, young women (mean ± standard deviation; age, 23.1 ± 1.9 years; height, 1.65 ± 0.08 m; mass, 63.1 ± 8.0 kg) participated in this study. To be included, participants had to have no current or recent (within the last two months) history of back or lower extremity pain or injury lasting more than two weeks. All participants were informed of the benefits and risks of the study and signed an informed consent form approved by Boston University’s Institutional Review Board prior to participation.

Instrumentation
Three-dimensional kinematic data of the trunk, pelvis, and lower extremity were recorded at 100 Hz using a 10-camera motion capture system (Vicon Motion Systems Ltd., Centennial, CO). Ground reaction force data were collected using the force plates in a split-belt instrumented treadmill (Bertec Corporation, Columbus, OH) sampling at 1000 Hz.

Procedures
Forty-two retroreflective markers were placed on the participant’s trunk, pelvis, and lower extremities based on the marker placement of a previous study.
A standing static calibration trial was recorded to create a subject-specific model. Markers on the medial knees and ankles were removed after the calibration trial to allow for freer movement.

For the three SLS tasks, participants were asked to stand on the treadmill force plates with each foot on a plate. Participants were instructed to stand on one leg, maintain their non-stance leg in one of three positions (Figure 1), and squat as low as possible in a controlled manner while keeping their arms at or out to their sides. The three non-stance leg positions were (1) the non-stance leg extended out front (SLS-Front) (Figure 1A), (2) the non-stance foot held in line with the ankle of the stance leg (SLS-Middle) (Figure 1B), and (3) the non-stance knee flexed 90° while maintaining a vertical thigh position (SLS-Back) (Figure 1C). Similar non-stance leg positions have been used in previous SLS studies. For example, SLS-Front was used by Crossley et al., SLS-Middle was used by Mauntel et al., and SLS-Back was used by Graci et al. These three non-stance leg positions likely represent most of the variation in non-stance leg positioning across clinicians. Verbal feedback was given to help participants maintain a consistent speed while completing the SLSs in a smooth, fluid motion. Five trials of each SLS task were collected. A trial was recollected if the participant lost her balance, did not position the non-stance leg correctly, or performed the SLS in a jerky or non-continuous manner. The order of the SLS tasks was block randomized. Both legs were tested; however, preliminary analysis showed no side differences between the squats performed on the left and right legs. Thus, the left stance leg was arbitrarily chosen for analysis of the hip, knee, and ankle data in this study.

**Data Processing**

Kinematic marker data were labeled using Vicon Nexus (Version 1.8.5). Kinematic and kinetic data were processed using commercially available software (Visual3D, C-Motion, Rockville, MD). Marker trajectories were filtered using a low-pass, fourth-order Butterworth filter with a cutoff frequency of 6 Hz. Hip, knee, and ankle joint angles were calculated with respect to the proximal segment. Pelvic and trunk segment angles were determined with reference to the lab coordinate system. All joint angles were calculated using a Visual3D hybrid model with a CODA pelvis and a right-handed Cardan X-Y-Z (mediolateral, anteroposterior, vertical) rotation sequence. The model consisted of eight rigid segments: a trunk, a pelvis, right and left thighs, right

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**Figure 1.** Three single leg squat (SLS) tasks: (A) SLS-Front, (B) SLS-Middle, and (C) SLS-Back.
The International Journal of Sports Physical Therapy | Volume 11, Number 2 | April 2016 | Page 204

and left shanks, and right and left feet. Ground reaction force data were low-pass filtered using a fourth-order Butterworth filter with a cutoff frequency of 10 Hz. Internal joint moments were calculated based on kinematic marker positions and ground reaction force data. Trunk, pelvic, hip, knee, and ankle angles as well as hip, knee, and ankle moments of the stance leg in all three planes were identified at peak knee flexion (PKF) using custom MATLAB code (The MathWorks, Inc., Natick, MA). In addition, all variables were extracted when the stance leg first reached 60° of knee flexion (60KF). Sixty degrees of knee flexion was selected because it corresponded to the approximate knee flexion angle achieved or minimum knee flexion angle required or targeted in previous SLS studies.7,8,15,19,20 In addition, a consensus panel of five physical therapists in a previous study13 agreed that a SLS must be performed to at least 60º of knee flexion to be clinically rated as “good.”

Statistical Analysis
Kinematic variables of interest were trunk, pelvic, and left hip, knee, and ankle angles in all three planes, at the two analysis points, PKF and 60KF. Kinetic variables of interest included left hip, knee, and ankle moments normalized to body mass in all three planes at PKF and 60KF. For each variable, a separate one-way repeated-measures analysis of variance (ANOVA) was used to compare the three SLS tasks at each of the two analysis points. The Mauchly’s Test of Sphericity was used to check for violations of sphericity. The Greenhouse-Geisser correction was applied if needed. A resulting significant main effect was followed by post-hoc Bonferroni-corrected paired t-tests to identify significant pairwise differences between the SLS tasks. Cohen’s d was used to compute the effect size (ES) of each pairwise comparison. As per Cohen’s21 suggestion, effect sizes of 0.2, 0.5, and 0.8 were interpreted as small, medium, and large changes, respectively. All statistical analyses were performed using SPSS, Version 20.0 (IBM Corporation, Armonk, NY). The alpha level was set at 0.05 for all tests.

RESULTS
The three variations of the SLS resulted in kinematic and kinetic differences at the trunk, pelvis, hip, knee, and ankle at PKF and 60KF (Tables 1 and 2). The Greenhouse-Geisser correction was applied to ankle eversion and ankle plantar flexor moment at PKF and ankle dorsiflexion and ankle inversion moment at 60KF. Results of the post-hoc tests and effect sizes of the pairwise differences between the SLS tasks are provided (Tables 3 and 4).

Kinematics
At PKF, the repeated-measures ANOVAs revealed significant main effects (p < 0.05) for kinematic variables of interest in the sagittal and frontal planes at the trunk, pelvis, hip, and knee, in the transverse plane at the hip, and in the sagittal plane at the ankle for the three SLS tasks and post-hoc analyses were performed. When the data were analyzed at 60KF, the differences across SLS tasks largely persisted except at the knee.

Trunk
SLS-Front resulted in less trunk flexion compared to SLS-Middle (ES = -0.43, p = 0.036) and less ipsilateral trunk flexion relative to the stance leg compared to SLS-Back (ES = -0.99, p < 0.001) at PKF. At 60KF, trunk flexion in SLS-Front was less than both SLS-Middle (ES = -0.58, p = 0.006) and SLS-Back (ES = -0.44, p = 0.016), but there was no difference in ipsilateral trunk flexion. In the transverse plane, there were no trunk differences at PKF or 60KF. ES for significant trunk differences ranged from small to large (ES = -0.99−-0.43).

Pelvis
At both analysis points, participants exhibited the greatest anterior pelvic tilt in SLS-Back and the least in SLS-Front, with SLS-Middle in-between (ES = -2.25−-0.73, p < 0.001). Greater contralateral pelvic drop relative to the stance leg (represented as positive on Tables 1 and 3) was observed in SLS-Back than SLS-Front and SLS-Middle at both PKF and 60KF (p < 0.001). The SLS-Front and SLS-Middle actually displayed contralateral pelvic hike at both analysis points. In addition, at 60KF, the contralateral pelvic hike was greater in SLS-Front than SLS-Middle (p = 0.002). There were no differences observed in the transverse plane for the pelvis at PKF or 60KF. ES for significantly different pelvic variables in the sagittal and frontal planes were generally large (ES = -3.02−-0.73).
Table 1. Descriptive statistics and main effect comparisons of kinematic variables of interest at 60° of knee flexion and peak knee flexion for the three single leg squat tasks.

<table>
<thead>
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<th>Joint angle (°)</th>
<th>Mean ± Standard Deviation</th>
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<tr>
<td></td>
<td>SLS-Front</td>
<td>SLS-Middle</td>
<td>SLS-Back</td>
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<td>Trunk flexion</td>
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<td>2.4 ± 2.5</td>
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<td>10.8 ± 7.5</td>
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<td>12.0 ± 7.9</td>
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<td>8.0 ± 6.8</td>
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<td>7.4 ± 7.9</td>
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<td>5.5 ± 9.7</td>
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<td>8.3 ± 2.7</td>
<td>9.1 ± 3.6</td>
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<td>9.9 ± 3.6</td>
<td>10.0 ± 4.5</td>
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<tr>
<td>60KF</td>
<td>8.7 ± 5.4</td>
<td>8.5 ± 4.3</td>
<td>9.3 ± 4.7</td>
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<tr>
<td>PKF</td>
<td>10.5 ± 5.6</td>
<td>10.6 ± 5.1</td>
<td>10.8 ± 4.8</td>
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</table>

Abbreviations: 60KF = 60° of knee flexion; ANOVA = analysis of variance; PKF = peak knee flexion; SLS = single leg squat
Note: Bolded text indicates a significant difference (p<0.05).
*Greenhouse-Geisser correction applied: F_{1.4,21.3}
*Greenhouse-Geisser correction applied: F_{1.5,21.8}
Hip flexion was greatest in SLS-Back, followed by SLS-Middle, and least in SLS-Front at PKF ($p \leq 0.009$) and 60KF ($p \leq 0.004$). Hip abduction was greater in SLS-Back than SLS-Front and SLS-Middle at both analysis points ($p < 0.001$). Hip external rotation was greater in SLS-Back than SLS-Front and SLS-Middle ($p = 0.001$) at PKF, but not at 60KF. These differences at the hip ranged from small to large (ES = -1.44−-0.33).

Knee flexion was least in SLS-Back compared to SLS-Front and SLS-Middle ($p = 0.009$) and 60KF ($p = 0.004$). There were no differences at the knee in the transverse plane at PKF or in any of the three planes at 60KF.

Ankle dorsiflexion was least in SLS-Middle compared to both SLS-Front (ES = 0.38, $p = 0.009$) and SLS-Back (ES = -0.20, $p = 0.014$) at PKF. There were no differences in ankle eversion or abduction at PKF. At 60KF, SLS-Middle had less ankle dorsiflexion than SLS-Back (ES = -0.40, $p \leq 0.001$). There was a significant main effect between the three SLS tasks for ankle eversion ($p = 0.049$) at 60KF, but pairwise comparisons revealed no differences. No difference was found in ankle abduction at 60KF. ES for

### Table 2. Descriptive statistics and main effect comparisons of kinetic variables of interest at 60° of knee flexion and peak knee flexion for the three single leg squat tasks.

<table>
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<tr>
<th>Normalized internal moment (Nm/kg)</th>
<th>SLS-Front</th>
<th>SLS-Middle</th>
<th>SLS-Back</th>
<th>Mean ± Standard Deviation</th>
<th>ANOVA</th>
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<tr>
<td>60KF</td>
<td>0.64 ± 0.34</td>
<td>0.74 ± 0.41</td>
<td>0.44 ± 0.30</td>
<td>19.8 &lt;0.001</td>
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<tr>
<td>PKF</td>
<td>1.05 ± 0.41</td>
<td>1.11 ± 0.54</td>
<td>0.79 ± 0.40</td>
<td>13.9 &lt;0.001</td>
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<td><strong>Hip abductor</strong></td>
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<tr>
<td>60KF</td>
<td>0.76 ± 0.12</td>
<td>0.75 ± 0.14</td>
<td>0.74 ± 0.14</td>
<td>1.0 0.383</td>
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<td>PKF</td>
<td>0.89 ± 0.14</td>
<td>0.87 ± 0.14</td>
<td>0.86 ± 0.16</td>
<td>1.4 0.268</td>
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<td><strong>Hip external rotator</strong></td>
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<tr>
<td>60KF</td>
<td>0.09 ± 0.13</td>
<td>0.20 ± 0.12</td>
<td>0.24 ± 0.10</td>
<td>42.7 &lt;0.001</td>
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<tr>
<td>PKF</td>
<td>0.11 ± 0.16</td>
<td>0.26 ± 0.14</td>
<td>0.28 ± 0.11</td>
<td>27.6 &lt;0.001</td>
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<td><strong>Knee extensor</strong></td>
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<tr>
<td>60KF</td>
<td>1.16 ± 0.24</td>
<td>1.20 ± 0.25</td>
<td>1.34 ± 0.22</td>
<td>22.4 &lt;0.001</td>
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<tr>
<td>PKF</td>
<td>1.52 ± 0.28</td>
<td>1.51 ± 0.30</td>
<td>1.59 ± 0.26</td>
<td>8.0 0.002</td>
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<td><strong>Knee adductor</strong></td>
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<tr>
<td>60KF</td>
<td>0.14 ± 0.20</td>
<td>0.14 ± 0.20</td>
<td>0.17 ± 0.23</td>
<td>2.1 0.135</td>
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<tr>
<td>PKF</td>
<td>0.34 ± 0.23</td>
<td>0.28 ± 0.24</td>
<td>0.26 ± 0.25</td>
<td>7.3 0.003</td>
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<td><strong>Knee internal rotator</strong></td>
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<tr>
<td>60KF</td>
<td>0.27 ± 0.05</td>
<td>0.30 ± 0.05</td>
<td>0.30 ± 0.05</td>
<td>5.9 0.007</td>
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<tr>
<td>PKF</td>
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<td>0.35 ± 0.05</td>
<td>1.0 0.367</td>
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<td>0.68 ± 0.21</td>
<td>0.54 ± 0.21</td>
<td>0.57 ± 0.23</td>
<td>13.8 &lt;0.001</td>
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<td>PKF</td>
<td>0.87 ± 0.23</td>
<td>0.71 ± 0.26</td>
<td>0.72 ± 0.24</td>
<td>16.1* &lt;0.001</td>
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<td><strong>Ankle inversion</strong></td>
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<td>60KF</td>
<td>0.26 ± 0.10</td>
<td>0.23 ± 0.08</td>
<td>0.24 ± 0.09</td>
<td>4.2* 0.044</td>
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<tr>
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<tr>
<td>60KF</td>
<td>0.08 ± 0.05</td>
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<td>0.10 ± 0.07</td>
<td>9.2 0.001</td>
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<tr>
<td>PKF</td>
<td>0.12 ± 0.08</td>
<td>0.11 ± 0.07</td>
<td>0.13 ± 0.06</td>
<td>2.7 0.080</td>
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Abbreviations: 60KF = 60° of knee flexion; ANOVA = analysis of variance; PKF = peak knee flexion; SLS = single leg squat
Note: Bolded text indicates a significant difference ($p<0.05$).
*Greenhouse-Geisser correction applied: $F_{1,5,22.1}$
†Greenhouse-Geisser correction applied: $F_{1,3,19.9}$
Table 3. Post-hoc pairwise comparisons and effect sizes of kinematic variables of interest at 60° of knee flexion and peak knee flexion for the three single leg squat tasks.

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<th>Joint angle</th>
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<th>SLS-Middle vs. SLS-Back</th>
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<td>0.15</td>
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Abbreviations: 60KF = 60° of knee flexion; ES = effect size; PKF = peak knee flexion; SLS = single leg squat.

Note: Bolded text indicates a significant difference (p<0.05).
significantly different ankle variables were generally small (ES = -0.40 – 0.38).

**Kinetics**
Differences in hip, knee, and ankle kinetics for the three SLS tasks were observed at both PKF and 60KF.

**Hip**
At both PKF and 60KF, the hip extensor moment was moderately greater in SLS-Front (ES = 0.63 – 0.64, p ≤ 0.002) and SLS-Middle (ES = 0.68 – 0.84, p < 0.001) compared to SLS-Back. There was no difference in the hip abductor moment for the three SLS tasks at either analysis point. The hip external rotator moment was smaller in SLS-Front compared to SLS-Middle (p < 0.001) and SLS-Back (p < 0.001) at both analysis points. These differences in the transverse plane were large (ES = -1.32 – -0.92).

**Knee**
At both analysis points, the knee extensor moment was greater in SLS-Back compared to SLS-Front (p ≤ 0.014) and SLS-Middle (p ≤ 0.003). These differences were small at 60KF (ES = -0.28 – -0.24), but moderate at PKF (ES = -0.78 – -0.57). The knee adductor moment was greater in SLS-Front compared to

<p>| Table 4. Post-hoc pairwise comparisons and effect sizes of kinetic variables of interest at 60° of knee flexion and peak knee flexion for the three single leg squat tasks. |
|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| Normalized internal moment | SLS-Front vs. SLS-Middle | SLS-Middle vs. SLS-Back | SLS-Front vs. SLS-Back |
| Hip extensor | Hip abductor | Hip external rotator | Knee extensor | Knee adductor | Knee internal rotator | Ankle plantar flexor | Ankle inversion | Ankle adductor | |
| 60KF | PKF | 60KF | PKF | 60KF | PKF | 60KF | PKF | 60KF | PKF |
| p | ES | p | ES | p | ES | p | ES | p | ES |
| 0.322 | -0.26 | &lt;0.001 | 0.84 | 0.002 | 0.63 | 1.000 | -0.13 | &lt;0.001 | 0.68 | 0.001 | 0.64 |
| &lt;0.001 | -0.92 | 0.137 | -0.36 | &lt;0.001 | -1.32 | &lt;0.001 | -1.27 |
| 0.425 | -0.05 | &lt;0.001 | -0.28 | &lt;0.001 | -0.24 | 1.000 | -0.18 | 0.003 | -0.57 | 0.014 | -0.78 |
| 0.094 | 0.23 | 0.745 | 0.11 | 0.002 | 0.34 |
| 0.036 | -0.55 | 1.000 | 0.02 | 0.029 | -0.56 |
| 0.001 | -0.69 | 1.000 | -0.07 | 0.005 | 0.64 |</p>
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</table>

*Abbreviations: 60KF = 60° of knee flexion; ES = effect size; PKF = peak knee flexion; SLS = single leg squat
Note: Bolded text indicates a significant difference (p<0.05).*
SLS-Back at PKF (ES = 0.34, p = 0.002), but not at 60KF. The knee internal rotator moment was moderately smaller in SLS-Front compared to SLS-Middle (p = 0.036) and SLS-Back (p = 0.029) at 60KF, but not at PKF.

**Ankle**
SLS-Front had a moderately greater plantar flexor moment than SLS-Middle (ES = 0.66 – 0.69, p ≤ 0.001) and SLS-Back (ES = 0.53 – 0.64, p ≤ 0.016) at both PKF and 60KF. The ankle inversion moments for the three SLS tasks were not different at PKF. Although there was a significant main effect between the three SLS tasks for the ankle inversion moment (p = 0.023) at 60KF, post-hoc tests revealed no pairwise differences. While there was no difference in the ankle adductor moment at PKF, the ankle adductor moments for SLS-Front (ES = -0.33, p = 0.005) and SLS-Middle (ES = -0.17, p = 0.007) were smaller than for SLS-Back at 60KF.

**DISCUSSION**
Although the SLS is often used in clinical assessments and rehabilitation, prior studies have not established if and how changing the non-stance leg position affects the way the SLS is performed. The aim of this study was to examine how participants perform the SLS when instructed to maintain the position of the non-stance leg in three ways and compare trunk, pelvic, and lower extremity kinematics and kinetics of the three variations of the SLS. The results confirmed the hypothesis, showing that the three SLS variations elicited distinct kinematic and kinetic demands throughout the trunk, pelvis, and lower extremity. The primary findings of this study were (1) SLS-Back had the most kinematic differences from SLS-Front and SLS-Middle, (2) SLS-Back had a smaller hip extensor moment than SLS-Front and SLS-Middle, (3) SLS-Back had a greater knee extensor moment than SLS-Front and SLS-Middle, and (4) the largest effects of changing the non-stance leg position were found at the hip and pelvis.

While previous studies have reported SLS kinematics, they often lacked specific details about the SLS procedure including the non-stance leg position. The current findings demonstrated that changing the position of the non-stance leg during the SLS had significant biomechanical effects throughout the trunk, pelvis, and stance lower extremity. Based on effect sizes, altering the position of the non-stance leg during the SLS had the greatest effects on pelvic kinematics, followed by hip kinematics. Overall, the largest effect sizes were observed between SLS-Front and SLS-Back for both pelvic anterior tilt and pelvic drop. At the pelvis, the difference between SLS-Front to SLS-Middle was larger for pelvic anterior tilt than pelvic drop, while the reverse was true when comparing SLS-Middle to SLS-Back. SLS-Front compared to SLS-Middle and SLS-Back showed large effect sizes for hip flexion, while SLS-Back compared to SLS-Front and SLS-Middle resulted in large effect sizes for hip adduction. Limited information about hip, knee, and ankle kinetics and ankle kinematics during the SLS is available in the literature. The current kinetic results provide practitioners with an indication of how different muscle groups are being stressed by the SLS variations. SLS-Back had a higher knee extensor moment than SLS-Front and SLS-Middle; thus, it may be a more appropriate SLS task when assessing the strength of the quadriceps. When assessing the strength of the gluteal muscles or hamstrings, SLS-Front and SLS-Middle may be more challenging than SLS-Back because they have higher hip extensor moments. Practitioners can use the hip, knee, and ankle kinetics and kinetics of the SLS variations, along with their angular momenta, to inform their selection of SLS tasks in order to create exercise plans that strengthen targeted muscles, are progressively challenging, or are more appropriate for individual patients. For example, the increased hip flexion and adduction during the SLS-Back may make it less appropriate for patients with femoroacetabular impingement (FAI) as hip flexion and adduction often elicits symptoms. Similarly, the decreased trunk flexion in the SLS-Front may be less appropriate for patients with anterior cruciate ligament (ACL) injuries since ACL forces and strains are higher when squatting with minimal forward trunk lean than with moderate forward trunk lean.
This study had several limitations. People with lower extremity pain, such as those with PFP, may use different movement strategies to perform the SLS variations than the asymptomatic participants in this study. Thus, caution should be taken when generalizing these results to symptomatic populations. While kinematic differences by sex have been reported for the SLS, this study focused on females only. Females have higher rates of PFP and noncontact ACL injury than males, so practitioners may encounter more female patients that may benefit from using different SLS tasks to address some of the biomechanical impairments including greater ipsilateral trunk lean, contralateral pelvic drop, hip abduction, and knee abduction identified by Nakagawa et al. Future studies should examine if these findings apply to males and if there are sex differences for the three SLS variations. While more complex, multi-segment trunk models exist, the trunk was modeled as a single rigid segment as commonly used in other SLS studies. Additionally, leg dominance was not considered in this analysis because preliminary data analysis of each leg revealed consistent findings for both sides. Finally, while instructions were given to control the position of the non-stance leg, none were given regarding the trunk, pelvis, and stance leg position during the three SLS tasks. This was done in order to more closely resemble how instructions for the SLS are given during clinical or field testing and to observe what modifications the individual naturally made following a change in non-stance leg position.

CONCLUSION
The results of the current study indicate that changing the position of the non-stance leg during the SLS results in different trunk, pelvic, and lower extremity biomechanics. Practitioners can use these results to better understand the biomechanical differences between the SLS variations and determine if certain variations may be more appropriate for individual patients, because not all SLS are equal. Applying these findings to athletes and patients may improve functional testing, as well as strength and rehabilitation paradigms.

REFERENCES


ABSTRACT

**Purpose/Background:** Lower limb asymmetry between dominant and nondominant limbs is often associated with injuries. However, there is a lack of evidence about frontal plane projection angle (FPPA) of the knee joint (knee valgus) during drop vertical jump (DVJ) and forward step-up tasks (FSUP) in young basketball players. Therefore, the purpose of this study was to assess the FPPA (i.e., dynamic knee valgus) via 2D video analysis during DVJ and FSUP tasks in the dominant and nondominant limbs of young male basketball players.

**Methods:** Twenty seven young male basketball players (age 14.5 ± 1.3 y, height 161.1 ± 4.1 cm, weight 64.2 ± 10.2 kg) participated in this study. The participants were asked to perform a bilateral DVJ and unilateral FSUP tasks. Kinematic analysis of FPPA was completed via a two-dimensional (2D) examination in order to evaluate the knee valgus alignment during the beginning of the concentric phase of each task. Knee valgus alignment was computed considering the angle between the line formed between the markers at the anterior superior iliac spine and middle of the tibiofemoral joint and the line formed from the markers on the middle of the tibiofemoral joint to the middle of the ankle mortise. Paired t-tests were used to evaluate differences in tasks. Standard error of measurement (SEM) was calculated to establish random error scores.

**Results:** There was no difference in knee valgus angle during the DVJ task between dominant (20.2 ± 4.4°) and nondominant legs (20 ± 4.1°; p = 0.067). However, a significant difference was noted during FSUP between the non-dominant limb (18.7 ± 3.4°) when compared to the dominant (21.7 ± 3.5°; p = 0.001) limb.

**Conclusion:** Two dimensional kinematic analysis of knee FPPA may help coaches and other professionals to detect asymmetries between dominant and nondominant limbs, and to develop training programs with the goal of reducing overall lower extremity injury risk.

**Level of evidence:** 2b

**Keywords:** Athlete development; injury prevention; knee; motor behavior; valgus moment

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INTRODUCTION
Basketball is a very popular team sport throughout the world, characterized by short and explosive efforts, agility, rapid changes of direction, as well as jumping and landing movements. Regardless of the specific motor skills, the jumping and landing abilities of these athletes are one of the key elements in successful basketball performance. However, excessive knee valgus or hip adduction during jumping, squatting, and lunging movements are often considered as a mechanism associated with lower extremity injuries.

Multiple contributing factors, such as previous injury, limb dominance, or specific sport demands, could result in the development of muscle strength imbalances among athletes. These imbalances not only may affect performance but also could increase incidence of injury. The majority of non-contact anterior cruciate ligament (ACL) injuries are reported in scientific literature as being associated with sports that involve rapid combinations of limb rotation movements, landing, or deceleration prior to change of direction (cutting) during agility tasks, such as basketball. Specifically, these injury mechanisms have been connected to excessive dynamic knee valgus (hip internal rotation, knee valgus or tibial rotation angles), contralateral pelvic drop, and a shift in the center of mass away from the stance limb induced by hip abductor weakness.

However, it is unclear whether these imbalances are a result of sport-specific training or of other factors such as injury or difference in leg length. Limb dominance is one of the factors that could impact lower limb strength imbalance, and consequently, affect injury risk. Possible reasons for bilateral strength asymmetries might be inadequate or incomplete rehabilitation program after injury with resultant differences in agonist-antagonist ratio, training methods, and specific motor demands of different sports. Limb dominance could be attributed to repeated use or emphasis on one lower extremity during sport, for example a leg being a drive leg for hitting, jumping, or base running tasks.

Previous authors have examined lower extremity imbalances via frontal plane kinematic analysis of the knee valgus collapse during dynamic tasks. Drop vertical jump (DVJ) is one of the tasks often utilized to assess athletic injury risk and performance capacity. Herrington used kinematic analysis to investigate knee valgus during DVJ and unilateral step landing tasks in elite female basketball and volleyball players. Basketball athletes in their study showed lower degree of knee valgus during unilateral step landing when compared to volleyball athletes. However, the authors found a greater knee valgus angle for the dominant limb when compared to the nondominant limb for the female basketball athletes during DVJ.

The forward step-up (FSUP) is an important daily activity that has been adopted as a closed-kinetic chain exercise during many rehabilitation programs. The FSUP is also used to assess hip and knee imbalances because it is characterized by hip and knee extension, and hip abduction and adduction in a dynamic, single-leg fashion, which is thought to elicit a high level of gluteus medius activation (i.e., > 60% of maximal voluntary contraction). Lin et al investigated the in vivo articular cartilage contact kinematics at the tibial plateau and femoral condylar surfaces during a FUSP activity in healthy subjects, by measuring the transepicondylar axis and the geometric center axis using a fluoroscopic imaging system. They noted that when the FSUP is performed without imbalances, medial and lateral compartments had similar motion patterns, avoiding the medial-pivoting motion (i.e., lower mobility of medial condyle in translation compared to the lateral side during flexion/extension of the knee). However, Luhahn et al reported that the weakness or poor synchrony of the rectus femoris, hamstrings, and hip abductor/adductor muscles during FSUP exercise caused excessive mediolateral or anteroposterior movement, and consequently a higher level of mechanical loads in tibiofemoral and patellofemoral joints, respectively. These conditions are functional and structural injury mechanisms often associated with traumatic ACL tears.

Understanding knee joint kinematics during step-up and jumping activities is important for optimizing rehabilitation protocols in order to enhance efficacy in treatment of common lower extremity injuries in sports, such as ankle sprains and ACL tear. However, there is still a lack of evidence about kinematic analysis of frontal plane projection angle (FPPA) of
the knee joint during DVJ and FSUP tasks between dominant and nondominant limb of young basketball players. Additionally, previous evidence indicates that individuals who exhibit high FPPA also demonstrate movement patterns that place increased stress on the ACL and patellofemoral joint, increasing risk of injury.\textsuperscript{5,20} Therefore, the purpose of this study was to assess the FPPA (i.e., dynamic knee valgus) via 2D video analysis during DVJ and FSUP tasks between dominant and nondominant limbs of young male basketball players. The authors hypothesized that young male basketball players would show greater knee valgus angle for the nondominant compared to the dominant limb during DVJ and FSUP tasks.

METHODS

Subjects
This observational study was designed to compare FPPA of knee joint during jumping and step-up tasks between dominant and nondominant limbs of young male basketball players was conducted at the Center of Kinesiology and Performance (NUCAR). Thirty-two young male basketball players (age 14.5 ± 1.3 y, height 161.1 ± 4.1 cm, weight 64.2 ± 10.2 kg) with background in regular strength or plyometric training volunteered to participate in this study. All participants had at least four years of basketball experience (4.5 ± 1.2 years), averaging four 60-min sessions per week. All participants were active in competitive sports training or were active in competition one to four times per week. The exclusion criteria adopted for the current study was: (a) potential medical problems or a history of ankle, knee, or back pathology that compromised their participation or performance tests proposed; (b) any lower extremity reconstructive surgery in the prior two years. Twenty-seven subjects met the inclusion criteria and were enrolled in this study.

Prior to data collection, the participants and their parents were informed about the experimental procedures and about possible risks and benefits associated with participation in the study and signed an informed consent before any of the tests were performed. The procedures were approved by the Institutional Ethics Review Committee of the Rio de Janeiro Federal University in accordance with the current national and international laws and regulations governing the use of human subjects (Declaration of Helsinki II).

Procedures
To simulate the jumping and lunging tasks that occur during athletic competitions, participants were asked to perform a bilateral DVJ and unilateral FSUP of both dominant and nondominant limb. Each participant was asked to perform three to five practice trials of both tasks.\textsuperscript{2} Once participants were familiarized with the tasks, they were asked to perform three test trials for each task; the sequence of unilateral FSUP (left or right leg first) or DVJ task was randomized for each participants.

The DVJ task was performed by having the subject stand on a 40-cm–high bench, the participant was then instructed to drop directly down off the bench on to a mark 40 cm from the bench, landing on both feet, and immediately perform a maximum vertical jump, raising both arms to provide countermovement (Figure 1). The FSUP movement involved the subject stepping up a 40-cm–high bench, and landing with the opposite leg on to a mark 40 cm from the bench (Figure 2). The subject stepped with the posterior border of the initial leg heel landing flush with the leading edge of the step box and with heel-to-toe foot

Figure 1. Frontal-plane projection angle during drop vertical jump.
position perpendicular to the leading edge of the box. The starting position was characterized by the trail leg in 10° hyperextension at the hip measured from the greater trochanter to the midline of the femur. The subject then extended the knee and hip of the initial leg until the trail foot was placed on the box lateral to the lead foot. The trail foot then returned to starting position, and the process was repeated. Although the definition of the dominant or preferred jumping leg is very important in the interpretation of test results, this distinction remains controversial in the literature.14 In the current study, limb dominance was operationally defined as the preferred kicking leg or the foot used for stair climbing.21

Kinematic analysis was performed via a two-dimensional (2D) FPPA of knee alignment measured during the DVJ and FSUP tasks. The reliability, measurement error, and validity of this 2D analysis has been previously established in comparison to three-dimensional (3D) measures.5 A digital video camera (Sony CX505VE32 GB HDD model; New York, NY, USA) was placed perpendicular to the subject’s knee (i.e., dominant and nondominant), two meters anterior to the participants’ landing target, and aligned perpendicular to the frontal plane. The digital images were imported into a digitizing software program (Quintic 4, Quintic Consultancy Ltd., Cambridge, England, United Kingdom), sampling at 30 Hz. Eight spherical markers were attached to the skin with double-faced adhesive tape at the following locations: the anterior superior iliac spine, the greater trochanter, the lateral femoral condyle, the lateral tibia condyle, middle of the tibiofemoral joint, middle of the ankle mortise, the lateral malleolus, and the fifth metatarsal.9 The verbal instructions proposed by Khuu, Musalem, Beach2 were adopted in the current study.

Knee valgus alignment was computed using the angle between the line formed between the markers at the anterior superior iliac spine and middle of the tibiofemoral joint and the line that formed from the markers on the middle of the tibiofemoral joint to the middle of the ankle mortise. The average knee valgus angle value from the three trials was used for analysis and computed for each leg during FSUP and DVJ tasks, respectively.20 Negative FPPA values reflected excursion of the knee away from the midline of the body, or varus alignment. On the other hand, positive FPPA values reflected dynamic knee valgus, excursion of the knee towards the midline of the body so that the knee marker was medial to the line between the ankle and thigh markers. The within-session reliability of this method has been described.5 All procedures were performed by the same researcher.

Statistical Analyses
Descriptive statistics (mean and standard deviation [SD]) were computed and presented for each dependent variable. The intraclass correlation coefficient (ICC = (MSb- MSW) / [MSb + (k-1) MSW]), where MSb = mean-square between, MSw = mean-square within, and k = average group size, was calculated to determine the reproducibility of intersubject for each measure. To evaluate differences between dominant and nondominant limb in knee valgus paired t-tests were used during both tasks. Standard error of measurement (SEM) was calculated to establish random error scores.20 The p-value was set at p ≤ 0.05. All statistical analyses were carried out using SPSS statistical software package version 20.0 (SPSS Inc., Chicago, IL).
RESULTS
The ICC’s and method errors are presented in Table 1. SEM scores ranged from 2.31° to 3.09° when examining the video analysis of DVJ and FSUP.

During the DVJ task there was no difference in FPPA between dominant (20.2 ± 4.4°) and non-dominant limbs (20 ± 4.1°) in the young basketball players tested (p = 0.067) (Table 2). However, a significant difference in FPPA was noted for nondominant limb (18.7 ± 3.4°) compared to dominant (21.7 ± 3.5°) limb during FSUP task (p = 0.001).

DISCUSSION
The purpose of this study was to assess the FPPA (i.e., dynamic knee alignment) via 2D video analysis during DVJ and FSUP tasks between dominant and nondominant limbs of young basketball players. The author’s hypothesis was that there would be a significant difference in knee valgus angle of nondominant versus dominant limb. The key finding from the current study was that a significantly greater FPPA was noted for the nondominant versus dominant limb (i.e., 16%) during FSUP task. However, there was no difference in FPPA between limbs during DVJ. This imbalance noted between dominant and nondominant limb during FSUP are in accordance in results from previous authors who found asymmetries between dominant and nondominant limbs during unilateral tasks performed by young athletes.7,21,22

Excessive knee valgus during dynamic tasks such jumping, running, and cycling has been reported in the scientific literature as a risk factor for sustaining lower extremity injuries in sports.3,8 Many studies use 3D motion capture methods to assess lower limb kinematics, which is expensive and time consuming to undertake, compared with 2D video analysis.20

Thus, the use of 2D video analysis has become more

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<th>Forward Step-up</th>
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<td>18.7 ± 3.4°</td>
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<tr>
<td>Nondominant</td>
<td>20 ± 4.1°</td>
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*Significant difference for dominant limb.

<table>
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<th>ICC</th>
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<tr>
<td>Forward step-up</td>
<td>0.91</td>
<td>(0.71, 0.91)</td>
<td>2.0 (2.9)</td>
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</table>

CVME: coefficient of variation of method error (percent variation in measurement between trials)
common as a simple, inexpensive, and reliable alternative for researchers, rehabilitation professionals, and coaches to investigate athletes’ injury-risk.  

Considering DVJ task, the results of the current study demonstrated no difference in FPPA between dominant (20.2 ± 4.4°) and nondominant leg (20 ± 4.1°). These data were similar to those noted by Khuu et al., Doherty et al., and Menzel et al who did not find differences in FPPA of knee joint and asymmetries between limbs during vertical jump tasks. On the other hand, the results of the present study demonstrated a significant difference in knee valgus angle was noted for nondominant limb (18.7 ± 3.4°) versus dominant limb (21.7 ± 3.5°) during FSUP task (16%). Pappas et al. and Newton et al both reported that knee valgus angles increases when unilateral step-up or step-down tasks are performed when compared with bilateral jumping tasks.

Step-up exercises are often adopted in rehabilitation programs due to the benefits of including loaded single-leg exercises to improve functional stability, providing the athlete a method to practice or improve dynamic control when supported by a single limb, as would occur during during unilateral landings and cuts, thereby offering the potential to reduce LE injury risk. Previous studies conducted with college athletes suggested that imbalances between dominant and nondominant limbs of 15% or more may increase the rate of lower extremity injury, especially in young athletes, making the 16% difference seen in the current subjects worth considering as potentially clinically relevant. Additionally, the step-up exercise requires unilateral support, as well as dynamic pelvic and trunk stabilization. The increased anterior tibial translation, medial tibial translation and external tibial rotation toward the end of the FSUP exercises is often associated with poor strength or recruitment of the rectus femoris, hamstrings, and hip abductor and adductor muscles. Such strength or recruitment issues should be addressed during rehab or sport preparation.

Regardless, the FSUP exercise is characterized by a greater concentric/eccentric component which occurs due to the additional range of knee extension and hip extension induced by the high bench when compared to the forward lunge performed on the floor. Simenz et al. reported that a large knee joint moment is generated together with a quadriceps-hamstring co-contraction in order to help stabilize the knee joint during FSUP exercise. Additionally, the final 45° of knee extension during the step up is often associated with an increase in patellofemoral joint compression, induced by resultant forces produced by quadriceps and patellar tendons. The tibial external rotation and increased strain in the medial collateral ligament may reduce the proprioceptors responses (i.e., muscle spindle and Golgi tendon organ) induced by the ACL strain due to a valgus moment at higher levels of valgus positioning.

There are potentially a multitude of reasons why an individual may demonstrate poor control of loading of the limb during FSUP including: poor proprioception, weakness or poor synchrony control of hip and knee stabilizers muscles (quadriceps, gluteus medius and maximus), and inadequate range of movement at joints such as the ankle resulting in compensatory movement patterns being adopted (i.e., asymmetry). MacAskill et al examined the role of the gluteus medius during dynamic movements such as jump landings and cuts, and reported that strengthening the gluteus medius may reduce the risk of ACL injury through the reduction in dynamic valgus position. Recently, Malloy et al suggested that training the gluteus medius may improve both strength and timing of gluteus medius activation, which may reduce dynamic knee valgus during sport and exercise, reducing risk of ACL injury.

The current study has limitations such the small sample size and the absence of measures such as muscle activation, ground contact time, and jump height during the DVJ and FSUP. However, a thorough understanding of the knee joint biomechanics during jumping and step-up activities is important for understanding presentation of normal athletes, and optimizing rehabilitation protocols so these results may assist many professionals who work with young athletes. Additionally, the findings of the current study regarding the asymmetries noted between dominant and nondominant leg during FSUP, may help conditioning and rehabilitation professionals to value the knee FPPA assessment using low cost and effective 2D kinematic analysis during tasks which exposes lower extremity injury risk.
CONCLUSION
The results of this study have shown a significant difference in FPPA of the nondominant limb when compared to the dominant limb during FSUP task performed by young basketball players. However, these differences were not found during a bilateral landing task the DVJ. These data indicated significant asymmetries between limbs during unilateral task. Therefore, the 2D kinematic analysis of knee joint alignment via FPPA during jumping, landing, lunging, and other unilateral tasks may help conditioning and physical therapists professionals to detect asymmetries between dominant and non-dominant limbs, and to develop training programs with the goal of restoring limb symmetry.

REFERENCES


ABSTRACT

Background: Dance is a physically demanding activity, with almost 70% of all injuries in dancers occurring in the lower extremity (LE). Prior researchers report that muscle function (e.g. muscle endurance) and anatomical factors (e.g. hypermobility) affect physical performance (e.g. balance) and can subsequently influence LE injury risk. Specifically, lesser core muscle endurance, balance deficits, and greater hypermobility are related to increased LE injury risk. However, the potential interrelationships among these factors in dancers remain unclear.

Purpose: The purposes of this study were to examine the relationships among core muscle endurance, balance, and LE hypermobility, and determine the relative contributions of core muscle endurance and LE hypermobility as predictors of balance in female collegiate dancers.

Study Design: Cross-sectional

Methods: Core muscle endurance was evaluated using the combined average anterior, left, and right lateral plank test time scores(s). LE hypermobility was measured using the LE-specific Beighton hypermobility measure, defining hypermobility if both legs had greater than 10° knee hyperextension. Balance was measured via the composite anterior, posterolateral, and posteromedial Star Excursion Balance Test (SEBT) reach distances (normalized to leg length) in 15 female healthy collegiate dancers (18.3±0.5yrs, 165.5±6.9cm, 63.7±12.1kg). Point-biserial-correlation-coefficients examined relationships and a linear regression examined whether core endurance and hypermobility predicted balance (p<.05).

Results: LE hypermobility (Yes; n=3, No; n=12) and balance (87.2±8.3% leg length) were positively correlated r(14)=.67, (p=.01). However, core endurance (103.9±50.6 s) and balance were not correlated r(14)=.32, (p=.26). LE hypermobility status predicted 36.9% of the variance in balance scores (p=.01).

Conclusion: LE hypermobility, but not core muscle endurance may be related to balance in female collegiate dancers. While LE hypermobility status influenced balance in the female collegiate dancers, how this LE hypermobility status affects their longitudinal injury risk as their careers progress needs further study. Overall, the current findings suggest that rather than using isolated core endurance-centric training, clinicians may encourage dancers to use training programs that incorporate multiple muscles - in order to improve their balance, and possibly reduce their LE injury risk.

Level of Evidence: 2b

Key Words: Beighton Score, lower body, plank tests, Star Excursion Balance Test

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INTRODUCTION
Dancing is a physically challenging activity.1,2 Dancers reportedly have a 90% lifetime injury incidence rate,3 with around 70% of all dance-related injuries occurring in the lower extremity (LE).4-6 Prior researchers have noted that neuromuscular (e.g. muscle endurance), anatomical (e.g. hypermobility) factors can influence motor performance (e.g. balance ability) and subsequently influence LE injury risk.7-12

The core musculature is important for stabilizing the LE during movement,13,14 and can influence LE injury risk.15 The muscles that collectively comprise the core include the transversus abdominis/internal obliques, rectus abdominus, external obliques, multifidus, and erector spinae muscles.13,16 Researchers12,16 have examined the effects of trunk and core-specific factors including proprioception on LE injury risk using logistic regression modeling. These researchers found that these factors were able to predict ligamentous knee injury (91% sensitivity, 68% specificity), and were able to predict knee injury risk with 84% accuracy, knee ligament injury risk with 89% accuracy, and anterior cruciate ligament injury risk with 91% accuracy in female athletes. As the terms core and trunk are often used interchangeably in the literature, for the current study the authors operationalized core endurance as the time that participants could maintain plank positions as described previously.17,18 Generally, higher scores on core musculature tests indicate better LE control during activity and may decrease LE injury risk.12,15,16

Balance and neuromuscular stability deficits also increase LE injury risk.7,8,11,19 As postural stability and balance are often used interchangeably, for this study the authors operationalized balance as the ability to maintain postural stability while standing on one leg and performing a reach with the other leg as described when performing the Star Excursion Balance Test (SEBT).20 Poor SEBT performance can predict increased LE injury risk, with prior researchers11 reporting that female athletes with lower (< 94% Leg Length, LL) reach distances are 6.5 times more likely to sustain a LE injury than female athletes with higher (> 94% LL) reach distances.11 Generally, previous researchers note that individuals with worse balance have a greater LE injury risk than those with better balance,11 and that improved balance decreases LE injury risk.7,8,11

Increased hypermobility can alter proprioception & balance,21,22 and is related to increased LE injury risk.10 In a systematic review and meta-analyses of generalized joint hypermobility and LE joint injury risk during sport, Pacey et al. reported that participants with generalized joint hypermobility had an increased risk of knee joint injury.10 Although dancers often are reported to be hypermobile,21,23 relatively little literature has examined if this hypermobility is an asset or liability.21,23 Some researchers24 have noted that when injured, female dancers with joint hypermobility syndrome had to stop dancing for longer periods of time than those without joint hypermobility syndrome. However, others25 have not found any differences in injury rates between hypermobile and non-hypermobile dancers.

In general, greater core muscle endurance and better balance is related to decreased LE injury risk, while greater hypermobility is related to increased LE injury risk. Dancers are a group of physically active individuals who commonly suffer LE injury. Still limited literature exists examining the potential interrelationships among core endurance, hypermobility, and balance in dancers. As the current authors wanted to examine how muscular and anatomical factors affect performance, we chose core muscle endurance and LE hypermobility as the predictor variables and balance as the predicted outcome measure for the study. Thus, the purposes of this study were to examine the relationships among core muscle endurance, balance, and LE hypermobility, and determine the relative contributions of core muscle endurance and LE hypermobility as predictors of balance in female collegiate dancers.

METHODS
Participants and Informed Consent
Fifteen healthy female collegiate modern dancers (18.3 ± 0.5 years, 165.5 ± 6.9 cm, 63.7 ± 12.1 kg, dance experience = 12.5 ± 4.6 years) participated in the study. All participants were volunteer dance majors and recruited from the same dance class at the university. While most dancers reported some prior injury in the past, at the time of testing they were injury free and did not have report any pain or issues that would affect their ability to perform the study tests. The local Institutional Review
Board approved all testing procedures and all participants provided informed consent. The authors used a cross-sectional study design. All tests were performed in a single session. The same examiners measured the same task for all participants.

**Balance**

Balance was measured via the Star Excursion Balance Test (SEBT) – and specifically – the Y-balance components of the test using previously published methods. The test required participants to first assume a single-leg stance, and then maximally reach along marked lines using the other leg while keeping the stance leg stable at the center of a grid, and then return the reach leg back to the center without losing balance. For this study, participants performed reaches in three reach directions: (a) anterior (b) posterolateral, and (c) posteromedial (Figure 1a, 1b, and 1c) in that order. The same investigator taught all participants to perform the test using both verbal instruction and demonstration, and participants were allowed three practice trials in each direction before actual test performance. A trial was not counted and asked the participant to repeat it if: (a) the participant was unable to maintain single leg stance, (b) the heel of the participants’ stance foot did not remain in contact with the floor, (c) the participants’ weight shifted onto the reach foot, or (d) the participant did not maintain start and return positions each for one second. The reach distances for the three trials in each direction were averaged and normalized to % leg length (LL). LL was measured from the anterior superior iliac spine to the medial malleolus. SEBT scores were combined across all directions bilaterally and this composite score was used for analyses.

**Core Endurance**

Core endurance was measured using plank tests in three positions: anterior (Figure 2a), right (Figure 2b) and left (Figure 2c) lateral using procedures described in prior literature. Participants first performed a single practice trial for a few seconds to confirm that they were able to successfully attain the test position. Then participants performed one recorded test trial. The maximum time (seconds, s) that the participants were able to hold and maintain the correct test position was recorded. The same examiner visually determined the end of all tests.
For the anterior plank test, participants assumed a push-up posture in the down position: legs together, lower leg in contact with a mat with ankles plantar-flexed, back straight, hands shoulder width apart, head up. Time recording was stopped when any segment of the participants’ body did not remain parallel to the floor as described in prior literature.17

To perform the left lateral plank test, participants placed their feet one on top of the other, their right arm perpendicular to the floor, with the elbow resting on the mat and the left arm across the chest with the left hand on the right shoulder. Participants used a similar position for the right lateral musculature plank test, with the left arm perpendicular to the floor. The time point when the participants could not maintain a straight line between the trunk or lower body (thigh or shank) segments on visual observation was recorded by the investigator.18 The average score of three tests was used for analyses.

Hypermobility
The lower extremity-specific item on the previously published Beighton Hypermobility tests (knee hyperextension >10° goniometry) was performed bilaterally and used to classify participants as LE hypermobile or not for this study.23,29 Specifically, participants were operationally defined as not LE hypermobile if one or neither knee hyperextended greater than 10° and LE hypermobile if both their knees hyperextended greater than 10°. The same investigator determined LE hypermobility for all participants.

STATISTICAL METHODS
Point-biserial-correlation-coefficients examined relationships among core endurance, LE hypermobility, and balance. A stepwise linear regression examined whether core endurance and LE hypermobility predicted balance. The relationships' strength was operationalized using previous guidelines, where 0.00-0.25 = little or no relationship; 0.26-0.50 = fair relationship; 0.51-0.75 = moderate to good relationship, and 0.76-1.00 = good to excellent relationship.30 An 0.05 alpha level was set apriori and the PASW 20.0 software (IBM Corp, Armonk, NY) was used conduct all analyses.

RESULTS
Three dancers (18.0 ± 0.0 years, 160.8 ± 8.4 cm, 58.2 ± 11.4 kg, dance experience = 14.3 ± 1.2 years)
were LE hypermobile, while 12 dancers (18.3 ± 0.5 years, 166.7 ± 6.4 cm, 65.1 ± 12.3 kg, dance experience = 12.0 ± 5.0 years) did not demonstrate LE hypermobility. See Table 1 for overall participants' descriptive statistics. LE hypermobility and balance (87.2 ± 8.3% LL) were positively correlated $r(14) = .67, p = .01$ to each other. However, core endurance (103.9 ± 42.5 sec) and balance (87.2 ± 8.3% LL) were not correlated $r(14) = .32, p = .26$.

The regression analyses revealed that LE hypermobility significantly predicted 36.9% of the variance in balance ($F_{1,13} = 9.20, p = .01$; standardized beta coefficient = .644, standard error = 6.58). LE hypermobility status was statistically coded with not LE hypermobile status = 0 and LE hypermobile status = 1. The regression model analyses resulted in the following equation: Balance score = 12.9 (LE hypermobile status) + 84.6. So theoretically, if a dancer's balance score – if she were not LE hypermobile – was 84.6% LL [12.9 * (0) + 84.6], then her balance score – if she were LE hypermobile – would be [12.9 * (1) + 84.6] = 97.5 % LL.

**DISCUSSION**

**Primary Findings**

The primary findings of the current study were that LE hypermobility and balance showed moderate to good positive correlations in collegiate female dancers. Core endurance and balance were not correlated in female dancers. LE hypermobility, but not core endurance, influenced balance in the study dancers.

**LE Hypermobility and Balance**

Twenty percent (3/15) of the study dancers were LE hypermobile. The authors purposefully chose only LE specific measures for the operational definition of hypermobility because of the interest in examining whether these LE specific measures influenced LE balance. If the dancers' hypermobility status was classified using the unabridged 9-point Beighton

<table>
<thead>
<tr>
<th>Test</th>
<th>Side</th>
<th>Direction</th>
<th>Mean</th>
<th>SD</th>
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<tr>
<td>SEBT Right</td>
<td></td>
<td>Anterior</td>
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<td>9.1</td>
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<td></td>
<td></td>
<td>Posteromedial</td>
<td>96.7</td>
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<tr>
<td></td>
<td></td>
<td>Posterolateral</td>
<td>95.6</td>
<td>10.5</td>
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<tr>
<td><strong>Average of Right Side Reaches</strong></td>
<td></td>
<td></td>
<td>87.5</td>
<td>9.0</td>
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<tr>
<td>SEBT Left</td>
<td></td>
<td>Anterior</td>
<td>69.9</td>
<td>8.8</td>
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<td>97.1</td>
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<td></td>
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<td>Posterolateral</td>
<td>94.7</td>
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<tr>
<td><strong>Average of Left Side Reaches</strong></td>
<td></td>
<td></td>
<td>87.2</td>
<td>9.6</td>
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<td><strong>Overall Composite Average of Right and Left Reaches</strong></td>
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<td>87.2</td>
<td>8.3</td>
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<tr>
<td>Core Endurance</td>
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<td>170.8</td>
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<tr>
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<td>Right Lateral Plank</td>
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<td></td>
<td></td>
<td>103.9</td>
<td>50.6</td>
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</table>
score criteria that also uses trunk and upper body measures to classify participants’ hypermobility (> 4/9). 46.7% (7/15) of the study dancers would have been categorized as hypermobile, close to the 2-44% hypermobility ranges in dancers noted by previous researchers. Based on the 9-point Beighton score, the LE hypermobile dancers’ Beighton score was 5.3 ± 0.6, the non-LE hypermobile dancers’ Beighton score was 2.8 ± 1.5, and overall all dancers’ Beighton score was 3.3 ± 1.8.

In the study participants, LE hypermobility and balance were positively related, and hypermobility status predicted 36.9% of the variance in their balance scores. Specifically, the LE hypermobile dancers had better balance than the non-hypermobile dancers. This finding was unexpected as prior researchers have indicated that increased hypermobility is associated with decreased proprioception. Part of the explanation for this finding may lie in the actual demands of the SEBT. The SEBT requires participants to reach as far as they can with one leg – and examines their functional stability strength limits and neuromuscular control. Previous researchers have found that individuals with hypermobility syndrome had higher passive knee ranges of motion than healthy controls. Thus, while the current authors did not explicitly record range of motion, the hypermobile participants in the current study may have had increased knee range of motion as reported in previous work, allowing them to reach farther on the SEBT. Still, how this knee hypermobility allows participants to maintain balance while reaching farther needs additional study.

How LE hypermobility status affects LE injury risk also remains unclear. Briggs et al. noted that while 50% of their hypermobile dancers had at least one tendon injury, only 21% of non-hypermobile dancers had at least one tendon injury. Also, they found that while 61% of hypermobile dancers took time off from dancing due to injury, only 32% of non-hypermobile dancers took time off for injury. The researchers suggested that although joint hypermobility may be associated with a better chance of getting selected as a dancer at the beginner levels, it may also be associated with higher injury risk and/or prolonged periods of recovery post-injury at elite levels. Combining the participant demographics of collegiate level dancers in the current study with this prior literature, it appears that while the LE hypermobile dancers in the current study may currently have better balance, they may be more vulnerable to greater LE injury risk as they progress in their dance careers.

The participants’ SEBT composite scores (87.2 ± 8.3% LL) were similar to previously reported score ranges (87.9 to 89.4% LL) in female collegiate athletes. Plisky et al. have reported that > 4 cm side-to-side differences in anterior reach scores predicted injury status in various sports. While the current authors did not examine LE injury, the dance participants’ anterior (right side = 87.5 ± 9.0, left side = 87.2 ± 9.6) and overall (right side = 70.0 ± 9.1, left side = 69.9 ± 8.8) reaches were remarkably symmetrical. One possible explanation for this observation could be that performing modern dance may be bilaterally challenging and thus not have required the dancers in the current study to have a dominant lower extremity, resulting in bilaterally symmetrical scores. Further, the study participants' composite reach scores (87.2 ± 8.3 were also close to 89.6% LL cut-off score reported by Butler et al. as the score below which an athlete was 3.5 more times likely to get injured than one who scored more. Thus, compared to prior literature, the dancers in the current study neither demonstrated side-side asymmetry nor had scores predictive of increased LE injury risk. Another factor to consider when comparing the current findings with those of McCormack et al. is the genre of dance performed by participants. The dancers in McCormack et al.’s study were ballet dancers, while the dancers in the current study were primarily modern/contemporary dancers. Similar to other types of athletics, where different sports have differing physical demands and subsequently different injury patterns (e.g. in tennis versus wrestling), different dance genres also have differing physical demands and injury patterns. Ballet dancers often perform repetitive LE-centric movements whereas modern/contemporary dancers often incorporate more upper and whole body movements. Therefore, it is possible that the physical demands of ballet may have placed hypermobile ballet dancers in the McCormack et al. study at different injury risk than the modern/contemporary
dancers in the current study. The clinical implication of this finding is that clinicians should consider their dancers' genre demands when treating them and designing training programs for them. Specifically, LE training programs can improve balance and decrease LE injury risk. Clinicians can thus identify hypermobile dancers early before the dancers become injured and design programs that use multiple muscle groups to improve their dancers' balance and possibly positively impact dancers' LE injury risk.

Core Muscle Endurance and Balance

The study participants' side plank core endurance scores (right: 75.7±37.8, left = 65.1±35 s) were similar to prior scores in healthy collegiate (right: 61±33, left = 66±38 s) and resistance trained females (right: 72±31, left = 77±35 s). The current study participants' anterior core endurance scores (170.8±78.7 s) were also close to previously published flexor core endurance scores in healthy collegiate (149±99 s) and resistance trained females (163±106 s). Consistent with prior work, the dance participants' core endurance scores had large standard deviations, possibly due to the nature of the tests that allowed participants to use different strategies to maintain test positions.

Theoretically, the greater the core musculature strength and endurance, the less the body has to compensate to maintain stability during perturbations and movement. However, core muscle endurance and balance were not related in the current study. The study findings are in agreement with other reports that core muscle function is not associated with balance. In contrast, Zazulak et al. did find that core stability did predict LE injury risk in female athletes. The difference between these observations may partly be due to the different measures of core function and stability used in these different studies and the lack of consensus in how to measure core stability in all research. Specifically, Ambegaonkar et al. used the McGill plank tests and Gordon et al. used the bent knee-lowering test to measure core function. Both these tests require participants to maintain core stability in a static (plank), or in a slow velocity dynamic position (bent knee lowering test). Conversely, Zazulak et al. used a sudden perturbation and examined the participant's ability to maintain or return to equilibrium after this perturbation in a seated position within a custom-made apparatus that fixed the participants' lower body. Core stability exists in a continuum where there the core muscles need to produce increasing amounts of force over decreasing amounts of time from core endurance to strength to power. The measures used in the current study, and by Gordon et al. and Ambegaonkar et al. were closer to the core endurance spectrum while the measure used by Zazulak et al were closer to the core power spectrum. Thus, it appears that core endurance may be less influential – and rather that core power, reaction ability, and neuromuscular control may be more influential in maintaining LE stability and subsequently have an effect on LE risk during activity.

In addition, Gordon et al. found that that hip external rotator muscle strength was moderately positively correlated to balance (SEBT reach distances). Other researchers have likewise noted that females with greater hip flexor, extensor, and abductor strength had better anterior and posterolateral SEBT scores. The researchers suggested that having females participate in hip muscle strengthening programs might improve their balance scores. Prior researchers also have noted that LE strengthening can improve balance, and that balance training, when used as part of a multi-intervention program can decrease LE injury risk. Hip muscle strength may be more influential in altering balance than core endurance. Overall, the practical implication of combining the findings of the current study with prior information is that instead of using extensive core endurance muscle-centric training, clinicians should use integrated training programs – that may include core power and reactive training as part of the program – to improve their dancers' balance and possibly decrease their dancers' LE injury risk.

Some of the limitations of this study include the small sample size (LE hypermobility was identified in only three participants), and the limited generalizability of the study findings to other groups. In the current study, the authors also used anterior and lateral plank tests to examine core musculature. Other tests exist in the literature that examine the 'core'. We specifically chose the plank tests as they are...
commonly used in the literature, and are valid global core muscle function measures, and activate the abdominal muscles. Furthermore, plank tests are easy to administer, and it is relatively easy to ensure that participants are using proper technique when performing the tests. Still, whether other tests such as those suggested by McGill may be more appropriate to examine core endurance in dancers needs study. Other muscles may also have influenced core endurance. For example, different dancers may have used their shoulder and leg musculature differently to maintain their bodies in the plank position. Thus, researchers should examine other test positions that isolate the core muscles and those positions that use core muscles as part of a functional chain to examine the core muscles’ role in influencing balance and motion. The authors of the current study also chose to use only two of LE-specific items from the 9-item Beighton scale to define LE hypermobility. Thus, the current findings are limited to only the LE and cannot be generalized to overall hypermobility.

The current authors also did not record ranges of motion of the dance participants. As some prior work indicates that ankle dorsiflexion ranges influence SEBT scores, future investigators should examine the role of joint ranges of motion and their influence on balance. While participants did have adequate rest between tests, researchers should also examine whether fatigue may have altered SEBT and core endurance test performance. Finally, while the current authors chose a valid and reliable balance test that allowed for comparisons of the current findings to prior work, future researchers may also consider other tests more closely related to dance movements to examine dancers’ balance.

**CONCLUSIONS**

The results of the current study demonstrated that LE hypermobility, but not core muscle endurance may be related to balance in female collegiate dancers. Although the LE hypermobile dancers in this study had better balance than non LE hypermobile dancers, how this hypermobility affects their LE injury risk as they progress in their dance careers needs longitudinal study. As core muscle endurance was not related to balance, the current findings indicate that rather than using isolated core endurance-centric training, clinicians may encourage dancers to use training programs that incorporate multiple muscles in order to improve their balance, and possibly reduce their LE injury risk.

**REFERENCES**


ABSTRACT

Background: Alterations in glenohumeral (GH) rotation especially internal rotation and total range of motion have been associated with altered GH kinematics and susceptibility to injury. Researchers have evaluated long-term change in baseball and tennis players, and short-term changes in baseball players. However, acute (short-term) changes in GH rotation have not been evaluated in tennis players.

Hypotheses/Purpose: The purpose of this study was to quantify short-term glenohumeral rotational changes within a group of professional women’s tennis players following competitive play. It was hypothesized that there would be acute alterations in passive glenohumeral internal rotation and total range of motion following episodes of tennis play.

Study Design: Cohort Study

Methods: Passive glenohumeral external rotation (GER), glenohumeral internal rotation (GIR), and total range of motion (TROM) were evaluated in a cohort of 79 professional adult female tennis players. Measurements were taken at three different time points (TP): baseline before match play (TP1), immediately after match play (TP2), and 24-hours after baseline (TP3).

Results: There was a statistically significant decrease in the mean GIR from TP1 (43 ± 11°) to TP2 (39 ± 9°) (p=0.002) and from TP1 to TP3 (38 ± 10°) (p=0.001). All measures were at the level of minimal detectable change (MDC) (4°) indicating clinical significance. There was a decrease in mean TROM from TP1 (146 ± 11°) to TP2 (142 ± 12°) (p=0.04), which was not above MDC (7°). Subgroup analysis showed that 47% of the players demonstrated a decrease in GIR beyond MDC, and 37% demonstrated a decrease in TROM beyond MDC. GER remained unchanged across all time points (p>0.05).

Conclusion: Both GIR and TROM were reduced after acute exposure to tennis play. In a large subgroup of the cohort, the changes were clinically significant and approached values previously demonstrated to be associated with increased injury risk. Given the changes in glenohumeral motion following acute exposure to tennis, evaluation of players for significant motion alterations following overhead activity and intervention strategies to minimize such alterations in these players are recommended for high level tennis players.

Level of evidence: Level 3

Keywords: Glenohumeral range of motion, tennis, tournament play, shoulder
INTRODUCTION
The inherent demands of competitive tennis require high velocities and large ranges of motion at the glenohumeral (GH) joint. Rotational velocities of up to 2420°/sec have been reported to occur during the service motion.1 These rotational velocities occur through a total range of motion of approximately 165° of glenohumeral internal rotation (GIR) and external rotation (GER).2 The forces and motions generated at the shoulder are essential, and must be produced for optimal performance. The anatomic structures around the shoulder have been shown to respond and adapt to these demands, with one response being alterations in motion. Alteration or loss of GIR and/or total range of motion beyond a certain point may be associated with altered joint kinematics3 and have been associated with shoulder injury in overhead athletes.4,5,6 Therefore, it is important to understand the result of tennis play on GIR and GER as a basis for rehabilitation, conditioning, and possible prevention strategies.

GER and GIR are commonly assessed both actively and passively in order to objectively quantify glenohumeral rotation. The sum of GIR and GER is referred to as the total range of motion (TROM). Several studies have shown that as GER increases, GIR decreases in the dominant arm of the asymptomatic overhead athlete.7-11 This alteration in motion appears to be an adaptive response to the imposed demands of the overhead athlete. There are several different theories regarding this rotational alteration including posterior capsule tightness,12,13 bony adaptations,7,11,13,15 and muscular weakness and tightness.13-15 Controversy exists as to which of these phenomena causes the altered motion; however, authors have documented that loss of GIR4,16,17 or TROM5,6 beyond a certain point is associated with shoulder injury. A GIR deficit ≥ 25° in the dominant shoulder compared to non-dominant has been identified as a risk factor for upper extremity injury in high school baseball players.17 Additionally, a TROM side-to-side deficit ≥ 5° has been linked to a higher risk of shoulder injury in elite baseball and handball players.5,6 However, these values have not been established in tennis athletes.

Changes in GIR and TROM have been documented within seasons in both baseball pitchers18,19 and tennis players.20,21 In addition, short-term studies have shown that GIR and TROM have been shown to decrease immediately following a throwing episode in baseball players.8,22-24 However, no information has been reported on the acute effects the overhead motion has on rotation in tennis. However, the previously mentioned studies have focused mainly on the changes in male overhead athletes. In addition to the large ranges of motion required to perform the tennis serve, the shoulder is a common site of injury in both male and female tennis players.25,26 Therefore, the purpose of this study was to quantify short-term glenohumeral rotational changes within a group of professional women’s tennis players following competitive play. It is hypothesized there would be acute alterations in glenohumeral internal rotation and total range of motion following episodes of tennis play.

METHODS
Seventy-nine professional women’s tennis players (age, 25±4 years; height, 174±6 cm; weight, 65±6kg) were recruited at four professional tournaments for participation in this study. Players were excluded from the study if they reported having sustained a shoulder injury or surgery within the previous three months. All subjects read and signed an informed consent form approved by the Lexington Clinic Institutional Review Board prior to participation in the study.

One examiner (SMR) measured passive GIR and GER on the dominant shoulder using a digital inclinometer (Dueler IQ,J T ech, Salt Lake City, UT). GIR and GER measurements were obtained at three different time points (TP): baseline immediately before match play (TP1), immediately after match play (TP2), and 24-hours after baseline (TP3). TROM was calculated as the sum of GIR plus GER.

Each subject was placed in a supine position on a treatment table. The elbow was placed in 90° of flexion and the glenohumeral joint in 90° of abduction with the humerus supported by a towel to maintain proper positioning of the joint.27,28 The examiner stabilized the scapula by cupping the coracoid process and posterior spine of the scapula with one hand.29,30 The other hand placed the inclinometer just proximal to the wrist and the subject was asked to relax
while the humerus was passively moved into GIR (Figure 1) and GER. GIR and GER measurements were taken to the point of tightness in which no more GH motion would occur without movement of the scapula. This procedure was performed once bilaterally at each time point. A single examiner positioned the arm, read the inclinometer, and recorded the measurements, made possible by the small size of the digital inclinometer used (Figure 1).

Intra-rater reliability of the examiner (SMR) was established by measuring 13 shoulders on two separate days. Intraclass correlation coefficient (ICC$_{2,1}$), standard error of measure (SEM), and minimal detectable change (MDC) values were calculated for GIR (ICC$_{2,1}$ = 0.801, SEM = 2.8°, and MDC = 4.0°) GER (ICC$_{2,1}$ = 0.915, SEM = 4.7°, and MDC = 6.6°), and TROM (ICC$_{2,1}$ = 0.919, SEM = 4.7° and MDC = 6.6°). Therefore, rotational measurements greater than or equal to 4° for GIR and 7° for TROM were considered to be a meaningful change.

**STATISTICAL ANALYSIS**

The Shapiro-Wilk test for normality was computed, confirming that the data were normally distributed. A one-way repeated-measures ANOVA was used to determine change in GIR, GER, and TROM across time (TP1, TP2, and TP3). All data were analyzed using the Statistical Package SPSS version 21 (IBM Corp. Armonk, NY, USA). An $\alpha$ level of 0.05 was considered significant for all statistical analyses.

**RESULTS**

Mean GIR significantly decreased from TP1 to TP2 ($p=0.002$) and from TP1 to TP3 ($p=0.001$) (Table 1). The changes from both TP1 to TP2 and TP1 to TP3 were at or beyond the level of MDC. Further analysis subdivided the subjects into those whose GIR decreased beyond the MDC (≤4°), increased beyond the MDC (≥4°), or stayed within the MDC (-3 to 3). Forty-eight percent and forty-seven percent of the players demonstrated a decrease in GIR between TP1 to TP2 and TP1 to TP3, respectively. Seventeen percent and twenty-four percent of the players demonstrated an increase in GIR between TP1 to TP2 and TP1 to TP3, respectively. The mean change of players that demonstrated decreased and increased GIR beyond the MDC of 4° is depicted in Figure 2.

**Table 1. Glenohumeral Range of Motion Comparisons across three time points measured in degrees**

<table>
<thead>
<tr>
<th></th>
<th>Baseline before match play (TP1)</th>
<th>Immediately after match play (TP2)</th>
<th>24-hours after baseline (TP3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Rotation(°)</td>
<td>43±11</td>
<td>39±9$^a$</td>
<td>38±10$^b$</td>
</tr>
<tr>
<td>External Rotation(°)</td>
<td>102±9</td>
<td>102±11</td>
<td>104±10</td>
</tr>
<tr>
<td>Total Range of Motion(°)</td>
<td>146±11</td>
<td>142±12$^c$</td>
<td>143±11</td>
</tr>
</tbody>
</table>

Data are presented as Mean ± Standard Deviation

TP = Time Point

$^a$Significantly different from TP1 ($p=0.002$)

$^b$Significantly different from TP1 ($p=0.001$)

$^c$Significantly different from TP1 ($p=0.04$)
and Figure 3. Thirty-five percent and twenty-nine percent of the players demonstrated changes in GIR that were within the MDC between TP1 to TP2 and TP1 to TP3, respectively.

GER remained unchanged from TP1 to TP2 and TP1 to TP3 (p > 0.05) (Table 1). TROM significantly decreased from TP1 to TP2 (p = 0.04), but there were no significant changes from TP1 to TP3 (p = 0.13) (Table 1). Thirty-seven percent of the players demonstrated a decrease beyond the MDC between TP1 to TP2 (Figure 4). Fourteen percent demonstrated an increase beyond the MDC, and 49% stayed within the MDC when investigating TROM. The mean change of players that demonstrated decreased and increased TROM beyond the MDC of 7° is depicted in Figure 4.

DISCUSSION
The results of this study demonstrate that acute exposure to tennis play results in change in key components of glenohumeral motion. GIR appears to be the most affected, although TROM also significantly changed from TP1 to TP2. These results are consistent with the previous literature that described adaptations to athletes in other overhead sports, which are believed to occur as a result of capsular, osseous, and musculotendinous alterations in response to repetitive overhead motion. Furthermore, this study adds novel information that subgroups of the larger tennis cohort may be more affected, and have exhibited higher levels of change.

The group mean for GIR decreased immediately after play and continued to decrease 24 hours after the acute match exposure. The group changes were only at the level of MDC, which may introduce doubt regarding the clinical significance of the changes. However,
when the group changes were subdivided based on increase or decrease outside the MDC, it was found that approximately half of the athletes demonstrated decreased GIR at levels approaching concern for injury risk. The group mean for TROM also decreased immediately after play and increased by 1° 24-hours following match play. These group changes were below the level of MDC, which also casts doubt on the clinical significance across the group. However, subgroup analysis showed that a little over a third of players demonstrated decreases in TROM, averaging 13 ± 6°. The data also demonstrate that tennis play does not appear to result in meaningful changes in GER following match play. This is consistent with other literature regarding changes in GH motion after acute athletic exposure.22,23 The observed decrease in GIR coupled with a lack of change in GER may be due to the nature of the forces applied to the shoulder during the overhand motion.1,2

Although there is still some controversy regarding the exact role of altered glenohumeral range of motion in performance and injury risk in overhead athletes, several points have been presented and discussed within the literature. First, most of the alterations involve decrease in GIR, either absolute or in relation to the opposite side, and decreased TROM in relation to the opposite side.5,6,17,22-24 Second, this alteration in GIR and TROM beyond a certain point is associated with increased injury risk at both the shoulder and elbow when assessing side-to-side deficits.5,6,17 Although exact values in GIR deficit linked to injury risk vary in the literature, it has been established that TROM deficit greater than 5° is associated with increased injury risk.5,6 Finally, these changes are also associated with decreased shoulder strength and increased muscle stiffness, which may be considered independent variables contributing to shoulder and elbow injury.19,31,32

The subgroup analysis revealed that some players decreased and some increased in motion while others remained relatively stable. However, nearly half of the players demonstrated a decrease in GIR motion across time that raises concern with the potential for adverse consequences. There are probably many factors responsible for the variability in the changes, including intensity of athletic exposure, local strength deficits, kinetic chain alterations, participation in regular conditioning activities, or the amount of previous play during the season. Until these factors are better identified, clinicians treating tennis athletes should evaluate all players for post match alterations, identify which players exhibit the significant negative changes, and implement effective interventions. This variability in motion change may also be one of the reasons behind the varied findings comparing altered motion and injury within the current body of literature.5,17,34

The researchers did not attempt to establish the anatomic or physiological basis for the changes in motion, only that they did occur. Exact mechanisms that create the acute alterations are not well established, but the amount and timing of the acute change suggest a musculoskeletal adaptation.43 This has implications for the content and timing of the interventions. Interventions should be implemented early, within the first 24 hours following tennis play, and are suggested to include dynamic warm-up, mobilization, stretching, light eccentric strengthening, and scapular retraction control.33,35-37

There are several limitations to this study. The first is that the study population was comprised of only female tennis players, so only general comparisons of the similarity of the adaptations can be made to previously studies using male baseball players, and no conclusions can be made regarding male tennis players. Second, this was an observational, cross sectional study involving change over 24 hours. More investigation is needed to examine what changes may occur in the short term (3-7 days) or long term (1-2 seasons). Third, because tennis players generally play every day or every other day, while baseball players generally pitch every 3rd to 5th day, the change over time may be different. Longer-term studies, over a weeklong tournament and over an entire season, and similar studies in male tennis players would help to provide additional missing information. Lastly, match time or other measures of match...
intensity were not collected during this investigation. Future reports should examine whether match time or intensity plays a role in objective glenohumeral alterations.

CONCLUSIONS
The demands of the overhead tennis serve motion result in acute adaptive changes in glenohumeral ROM in female tennis players. Female tennis players demonstrated decreased GIR and TROM, similar to the direction of change previously found in male baseball players.22 Given the concern regarding the possible impact of changes in glenohumeral ROM on shoulder and elbow injury risk in baseball players, evaluations for this change, identification of the patients exhibiting the change, and intervention strategies to minimize the motion alterations should be considered in tennis players as well.

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ABSTRACT

**Background:** Stretching is often part of the warm-up routine prior to athletic participation; however, controversial evidence exists on the effects of stretching on countermovement jump (CMJ) and sprint performance. Additionally, analysis of variability between repeated tasks is useful for monitoring players, to analyze factors that could affect the performance, and to guide clinical decisions for training strategies.

**Purpose:** The purpose of this study was to examine whether static stretching (SS) prior to CMJ and 20-meter (20-m) sprint would affect performance, and to investigate whether SS affects an athlete's ability to perform these tasks consistently.

**Methods:** Twenty-two trained healthy athletes (23.2 ± 5.0 years) attended, randomly, two testing sessions, separated by 48 hours. At session one, all participants underwent 10 minutes of dynamic running warm-up followed by the experimental tasks (three CMJ and three 20-m sprint), whereas five minutes of stretching was added after the warm-up routine at session two. All participants performed the same experimental tasks in both sessions. The stretching protocol consisted of five stretching exercises for each lower limb.

**Results:** The paired-samples t-test revealed no significant differences between the stretching protocol condition and no stretching condition for the 20-m sprint (t(21)=.920; p=.368) and CMJ (t(21)=.709; p=.486). There were no significant differences in trial-by-trial variability on 20-m sprint (t(21)=1.934; p=.067) and CMJ scores (t(21)=.793; p=.437) as result of SS.

**Conclusion:** The SS protocol did not modify jumping and running ability in trained healthy athletes. The SS prior to training or competition may not cause detrimental effects to athletic performance.

**Keywords:** Counter movement jump, sports performance, sprint, static stretching, variability.

**Level of evidence:** Level III, Nonrandomized controlled trial.
INTRODUCTION
Planning an appropriate warm-up routine for an athletic team is a very important aspect of a coach's responsibilities since it prepares the athletes, physiologically and mentally for training and competition. Stretching is often part of the warm-up routine; however, few studies have reported beneficial effects of stretching on performance. Existing literature offers varied conclusions on the influence of stretching on jumping and speed performance. Both negative and no effects have been reported. In several cases, existing scientific evidence has not been taken into consideration with regard to stretching in the context of preparation for sports practice. For instance, to convince athletes about the importance of stretching prior to performing sports activities, coaches usually use empirical arguments that stretch improves performance, indirectly, by preventing injury.

Several authors have reported negative effects specifically with regard to vertical jump and sprint performance. Some hypotheses have been offered attempting to explain the negative effects of stretching on the neuromuscular system. According to Young & Behm stretching possibly induces an increase in slack on the tendon through a decrease of musculotendinous stiffness. Church et al suggested that the reduction of vertical jump performance may be related to the myogenic reflex, which causes a decrease in muscle power. In a review on the beneficial effects of stretching on performance, concluded that a bout of stretching does not improve jump height and the results on speed tasks are controversial; however, it does not mean that it is detrimental to performance. In fact, the supposition that stretching is harmful to performance has led to the removal of SS from the warm-up routines of many athletes. It may be that this kind of recommendation should be considered somewhat premature since the effects of SS prior to sports activities remain unclear.

The lack of consensus concerning the effect of SS on countermovement jump (CMJ) and 20-meter (20-m) sprint led the authors to investigate its influence on these functional abilities in order to examine whether SS is harmful to performance. Differing methodologies have been used to examine stretching effects on performance, such as varied stretching protocols (volume and intensity of stretching), numbers of performance trials, varied environmental conditions, and alterations in the rest period between each task. All of these factors may be responsible for generating divergence in the literature which hampers comparisons between investigations.

Athletes commonly use jump and sprint tasks as an assessment of their athletics skills. Some authors argue that the analysis of variability can be useful to determine whether athletic enhancement occurs. Because athletes wish to perform to the best of their ability or skill, it is also important to investigate whether stretching is a factor that may affect the athlete's ability to perform usual tasks consistently. To the authors' knowledge, no study has addressed how stretching affects the variability in CMJ and sprint tasks. Expecting to achieve a better understanding of responsible factors for an irregular performance, trial-by-trial variability analysis in the 20-m sprint and CMJ was included in this experiment.

The purpose of this study was to examine whether static stretching (SS) prior to CMJ and 20-meter (20-m) sprint would affect performance and to investigate whether SS affects an athlete's ability to perform these tasks consistently. Based on previous studies, the authors proposed the following hypotheses: 1) SS is detrimental to performance, which would be demonstrated by reducing CMJ height and 20-m sprint speed performance; 2) SS provides greater variability for both CMJ and 20-m sprint performance.

METHODS
All participants attended two testing sessions, completing three CMJ trials on a jump mat and three 20-m sprints on an indoor track, in each session. The Ergojump Platform (Globus Inc., Treviso, Italy) was used to measure the jumping time and indirectly the height reached in the CMJ by using the formula h = g * t^2 / 8, where h is height, g is gravity (g = 9.81 m/s^2), and t is the full flight time. For each CMJ, participants stood with hands on hips and feet parallel to landmarks on the mat of the Ergojump. They performed a squat with the knee in 90° of flexion and then jumped to achieve maximum height. Subjects were encouraged to jump as fast as possible in order to minimize the coupling time between
the eccentric and concentric phases, making sure not to pause between the movements. They were instructed to keep the hands on their hips because the literature has shown that the arms contribution during the vertical jump can add 10% or more to the outcome. They were also instructed to keep their hips and knees extended throughout the airborne part of the jump until the landing.

Two pairs of photoelectric cells (Ergo Timer, Globus Inc., Treviso, Italy) were placed at 90 cm height and connected to an electronic motion sensor timer, which measured the time needed to complete 20-m sprint. For this task, participants remained upright standing, in a steady and comfortable position, with feet behind the first line of photoelectric cells, without any rocking movements of the body. Participants started running on a whistle sound. Of note, reaction time was not included in the measurement.

Participants
Twenty-two healthy men took part in the study (age: 23.2 ± 5.0 years; body mass: 82.8 ± 12.6 kg; height: 1.78 ± 0.06 m; BMI: 26.1 ± 2.8 kg/m²). Participants were trained amateur athletes of different sports (e.g. handball, rugby sevens, etc.) and were recruited randomly through regional sports clubs. All of them were concurrently competing at the official national league of their sport. This population was recruited since their training and sport-specific participation often requires jump and speed abilities. Thus, it is expected they were familiar with the designed tasks (CMJ and 20-m sprint). To be included in the study, participants had to be: (a) aged 18 years or more; (b) physically active and registered as athlete at the official national league; (c) free of any medical condition or functional limitation that could compromise the testing tasks; (d) rested and not have performed any intensive physical activity for 48 hours prior to testing; (e) free of any injury or physical restriction at the time of testing. Researchers provided verbal encouragement at the same type and level for all players, to encourage maximal effort throughout testing. All participants received information about the research objectives and signed a consent form. The ethics committee of Faculty of Sports Sciences and Physical Education of the University of Coimbra approved this research, which is in agreement with the Helsinki declaration for experiences with humans.

Procedures
A summary of the experimental procedures is displayed in 1. At least three hours before testing, all participants joined a familiarization session with the measurement techniques and equipment. All participants underwent measurement of body weight (Body Scale 500, Seca GmbH & Co. Kg., Hamburg, Germany) and height (stadiometer Seca Body-meter 206, Seca GmbH & Co. Kg, Hamburg, Germany).

The data collection took place in two sessions separated by 48 hours to minimize fatigue effects on testing performance, in randomized order. Each day, before the experimental tasks, all participants performed a warm-up routine (dynamic running warm-up) similar to those performed for a normal training session. Dynamic warm-up consisted of the following exercises: a) jogging for one minute; b) skipping arm run for 30-sec; c) high knee run for 30-sec; d) knee flexion run (gluteal kicks) for 30-sec; e) sideways run for 30-sec; f) run with alternating squat for one minute; g) jogging forward/backward for two minutes; h) walking for one minute; i) running forward/backward for one minute; j) walking for one minute and trunk twist for one minute. It lasted 10 minutes and ended two minutes before the experimental tests began. The variability was calculated through analysis of the three trials of each condition, in both sessions.

![Figure 1](image-url)
Stretching protocol

Despite several stretching protocols applied in the literature, the SS is the most common stretching variation used in the examination of the stretching effects on performance.\(^5,30,31,36,39\) In this study, the SS was the only variation of stretching applied for a total time of five minutes after the warm-up. The stretching protocol followed the American College of Sports Medicine guidelines, and was chosen because it followed realistic parameters of stretching usually applied during the warm-up routine of athletes.\(^45\) Each participant performed one set of the stretches for each target muscle (triceps surae, quadriceps, hamstrings, gluteus maximus and quadratus lumborum). Each stretching was held for 30 seconds, without any bouncing, before changing immediately to the contralateral side. Prior to each stretch, the researcher demonstrated how to properly perform the motion. Participants were instructed to reach the point of slight discomfort and keep a stationary position, at maximum possible length, until they approached the end of the range of motion.

During the entire experimental protocol, a supervisor assured that each stretching technique was being performed properly. Three trials of both CMJ and 20-m sprint were then performed, in randomized order, to reduce the possibility of bias. A rest of two minutes was given between the tasks, as well as five minutes rest period before performing a new repetition of CMJ and 20-m sprint. The authors expected that the recovery time established could be enough to eliminate the cumulative effect of fatigue suffered in each trial.

Calf Stretch, Hands against Wall. (Triceps surae). Stand facing a wall from some feet away. Stagger your stance, placing one foot forward with the knee bent, while keeping the back leg straight. Lean forward and rest your hands on the wall, keeping your heel, hip and head in a straight line. Keep your heel on the ground with no bouncing. Switch sides.

Standing Quadriceps Stretch. (Quadriceps). Stand upright with feet crossed and extend your arm overhead. Place the other hand on the contralateral hip, crossing your abdomen. Bend your trunk laterally to the opposite side of the arm that it is extended over the head. Switch sides.

Sitting Toe Touch One Leg. (Hamstrings). Sitting with the upper body nearly vertical, right knee extended and left knee bent. Lean forward and attempt to grasp the right foot toes or right ankles (depending on the limits of flexibility). Switch sides.

Ankle on the Knee. (Gluteus maximus). From a lying position, knees bent and feet kept on the floor, place an ankle on the opposite knee. Grasp the thigh or knee of the bottom leg and pull both of your legs into the chest. Relax the neck and shoulders. Switch sides.

Statistical Analyses

Descriptive data are expressed as mean ± SD. All data were stored in a database and exported to the Statistical Package for the Social Sciences version 17.0 (SPSS Inc., Chicago, IL, USA) for detailed statistical analysis. Initially, the normality was confirmed by the Shapiro-Wilk test, which both CMJ and 20-m sprint presented normal distribution (\(p = .399; p = .266\), respectively). To examine the effect of the protocol on CMJ and 20-m sprint performance, with and without stretching, a Paired Samples t-test was used. Only the best performances for both conditions were taken for statistical analysis. Coefficient of variation quantified the variability of CMJ and 20-m sprint. Intraclass correlation coefficient (R) and the confidence intervals (95%) determined the reliability of the CMJ and 20-m sprint trials. Statistical significance was set at an alpha level (\(\alpha\)) of 0.05.

| Table 1. Intraclass correlation coefficients (R) for the Countermovement Jump and 20-m Sprint |
|-----------------------------------------------|---------|
| Countermovement Jump                          | R (95% CI) |
| Static stretching (SS) – No stretching        | .93 (.84 – .97) |
| 20-m Sprint                                   | .75 (.49 – .89) |
| R= intraclass correlation coefficient, CI= confidence interval |
RESULTS
Performance results are shown in Table 2. For the CMJ, no significant differences were noted between both conditions (stretching protocol and without stretching protocol) in terms of height reached (t(21) = .709; p = .486). The speed to complete the 20-m sprint performance also did not demonstrate significant differences between the conditions analyzed (t(21) = .920; p = .368). Neither the CMJ and 20-m sprint presented significant trial-by-trial variability (t(21) = .793; p = .437; t(21) = 1.934; p = .067, respectively) when the conditions were compared.

DISCUSSION
Results of the current study add evidence to a much-discussed issue regarding the usage of stretching prior to training or competition. In the present study, SS did not reduce the CMJ or 20-m sprint performance refuting the hypotheses that SS would have a detrimental effect on the performance of both tasks and would provide greater trial-by-trial variability. The authors believe that the lack of effects seen after the protocol may be due the duration, volume, and intensity of stretching. This reasoning is in line with previous studies.6,13,46 Stretching less than 30 seconds tends to not have an influence on performance in trained people.47 Authors have reported that three sets of 15 or 45 total seconds of stretching are not enough to provide alterations of the viscoelastic properties of muscle-tendon units (MTU).5,48 In addition, a study has been published that supported that 15 seconds has the same effectiveness than 45 or 60 seconds.49

Counter-Movement Jump
Current findings showed no significant effects of SS on CMJ performance (p = .709) (Figure 2), corroborating the observations from Shrier.37 A decreased eccentric force is expected after SS, due to the positive correlation between the musculotendinous stiffness and eccentric muscle performance.30 This could lead to a reduction in the jump performance. Based on this, Young & Behm31 argued their results reporting negative effects of SS (2 sets x 30 s) on CMJ. An important observation is that, in their study, only two minutes rest was given following each trial. Differing recovery time between trials is likely the reason for different results between our study and Young & Behm,31 since it is directly related to the recovery of motor neuron excitability, which has been presented as possible explanation for the unchanged performance following SS.5 Possibly, the recovery time adopted in the current research allowed the neuromotor excitability return to its basal level. Following this line of reasoning, the intensity of stretching is supposed to affect the CMJ performance; however, it is likely that the volume and intensity, or even the type of stretching used in the current protocol, were not enough to provide any physiological changes. Thus, it seems that a decrease of eccentric force sufficient to affect performance on the CMJ was not achieved in this investigation.

Current findings also corroborate the results from several studies with regard to vertical jump outcomes.5,16,18-24,46 The authors highlight the investigation from Unick et al,5 who examined 18 female basketball players from NCAA Division III in three conditions (non-stretching, static and ballistic stretching). The authors did not find a significant decrease at the vertical jump for the SS condition. Despite this, the comparison between the current results and those of Unick et al is not simple since

<table>
<thead>
<tr>
<th>Table 2. Comparison between the mean scores for Countermovement Jump height and 20-m Sprint speed. Values are represented as mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>Performance</td>
</tr>
<tr>
<td>Height – CMJ (cm)</td>
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<tr>
<td>Speed – 20-m Sprint</td>
</tr>
<tr>
<td>Trial-by-trial variability</td>
</tr>
<tr>
<td>Height – CMJ (cm)</td>
</tr>
<tr>
<td>Speed – 20-m Sprint</td>
</tr>
</tbody>
</table>

SS: static stretching protocol. NS: no stretching.
methodological differences exist. For instance, Unick et al\textsuperscript{5} used a sit and reach test plus five minutes warm-up jog, prior to the tests, both at a self-selected intensity. Moreover, they analyzed women only and some studies have shown that men tend to exhibit greater leg stiffness.\textsuperscript{50} Finally, their SS protocol consisted of three sets of 15 seconds, followed by a rest period of 15 minutes.

20-m Sprint

It is important to highlight that the term “reduction” with regard to sprint performance, varies according to the outcome analyzed. When the outcome is the “time” necessary to complete a sprint task, the term reduction means improved performance, whereas measuring the “speed” achieved during the sprint task, reduction means decreased performance. In the current study, the outcome measure related to the 20-m sprint performance was the speed, which recorded how fast the participants ran.

The stretching protocol did not provide a significant reduction in 20-m sprint performance (p = .920) (Figure 3), corroborating results from two previous studies.\textsuperscript{34,39} Wong et al\textsuperscript{39} evaluated the 30-m sprint performance of 20 soccer players after an SS protocol and found no negative effects caused by the SS. Little & Williams,\textsuperscript{34} submitted 18 soccer players to three different protocols (static stretching, dynamic stretching, and no stretching). Like Wong et al,\textsuperscript{34,39} Little & Williams\textsuperscript{34} did not find evidence that SS has a detrimental effect on sprint performance when included in a warm-up session.

Variability

Although a number of studies have examined the stretching effect on 20-m sprint speed and CMJ height performance, variability in these variables has not been ascertained. The current data adds information regarding the influence of SS on the variability of task performance, which is a missing issue in the literature. From the motor control perspective, it is supposed that extensive practice could provide better motor skills\textsuperscript{51} and more consistency in performing usual tasks. This would mean greater CMJ height, greater speed in the 20-m sprint and less variability between all measurements. Tasks performed often during daily training tend to present minimal or no variability in response to training. In contrast, the expected negative effects of stretch-
ing should cause inconstancy in the performance, and hence increase variability. The hypothesis that the SS group would demonstrate greater trial-by-trial variability was not confirmed as no statistically significant differences were found in trial-by-trial analysis of the either the CMJ or the 20-m sprint (t(21) = .793; p = .437; t(21) = 1.934; p = .067, respectively) (Figures 4 and 5).

One of the possible reasons for these results is the standardized resting period, established in the current investigation. The authors believe that this period might have allowed the return of the neuromotor excitability to its prestretching physiological status, since it has been suggested that a recovery interval greater than five but less than 15-20 minutes may provide ergogenic effects on short-term performance.52

Understanding the variability may bring interesting information for guiding a clinical decision making for training strategies.41 Variability of performance can be used for monitoring players, as well as designing and analyzing factors that could affect the athletic performance.53,54 Knowledge regarding variability emerges as useful information for the training

Limitations
Despite the rigorous methodological approach supported by a well-designed stretching protocol, some limitations were identified. For instance, only lower limbs were analyzed and, because the muscles fibers of the upper limbs present different characteristics, the effects of stretching on performance might be different. In addition, the performance in different sports was not compared and the specificity of each sport may affect the learning effects of CMJ and sprint tasks, which may have directly affected performance.

Future research
The effects of other stretching techniques on sports performance should be examined using the described experimental protocol in order to expand the scope of this analysis. In addition, upper limb stretches and the physiological mechanisms regulating the effects of stretching on CMJ and 20-m sprint should be further investigated to expand the

Figure 4. Performance in the three trials for the CMJ. Data are presented by mean ± SD. No significant difference exists between the trials and conditions (p = .437).

Figure 5. Performance in the three trials for the 20-m Sprint. Data are presented by mean ± SD. No significant difference exists between the trials and conditions (p = .067).
The magnitude of acute effects of SS should be compared with the effects that may have been induced by other warm-up components. Comparison between different stretching magnitude and intensity, as well as different duration and volume of stretching prior to training, should be also further examined in order to identify potential influence on performance.

CONCLUSION

The results of the current study provide evidence that SS does not reduce jumping and sprinting performance when performed after a warm-up routine. The authors concluded that SS, under the experimental conditions applied in the study, did not cause any detrimental effects on either the CMJ or the 20-m sprint. Additionally, SS does not lead to significant changes in the trial-by-trial variability of CMJ or 20-m sprint performance.

REFERENCES


ABSTRACT

Background: The application of Kinesio Tex® tape (KT) results, in theory, in the improvement of muscle contractibility by supporting weakened muscles. The effect of KT on muscle strength has been investigated by numerous researchers who have theorized that KT facilitates an immediate increase in muscle strength by generating a concentric pull on the fascia. The effect of KT on balance and functional performance has been controversial because of the inconsistencies of tension and direction of pull required during application of KT and whether its use on healthy individuals provides therapeutic benefits.

Hypotheses/Purpose: The purpose of the present study was to investigate the immediate and long-term effects of the prescribed application (for facilitation) of KT when applied to the dominant lower extremity of healthy individuals. The hypothesis was that balance and functional performance would improve with the prescribed application of KT versus the sham application.

Study Design: Pretest-posttest repeated measures control group design.

Methods: Seventeen healthy subjects (9 males; 8 females) ranging from 18-35 years of age (mean age 23.3±0.72), volunteered to participate in this study. KT was applied to the gastrocnemius of the participant's dominant leg using a prescribed application to facilitate muscle performance for the experimental group versus a sham application for the control group. The Biodex Balance System and four hop tests were utilized to assess balance, proprioception, and functional performance beginning on the first day including pre- and immediately post-KT application measurements. Subsequent measurements were performed 24, 72, and 120 hours after tape application. Repeated measures ANOVAs were performed for each individual dependent variable.

Results: There were no significant differences for main and interaction effects between KT and sham groups for the balance and four hop tests.

Conclusion: The results of the present study did not indicate any significant differences in balance and functional performance when KT was applied to the gastrocnemius muscle of the lower extremity.

Level of evidence: Level 1- Randomized Clinical Trial

Keywords: Balance, functional performance, kinesiotaping
INTRODUCTION
Balance is defined as the ability to keep the body's center of mass within the limits of an individual's base of support. The ability to balance is necessary for a variety of functional activities of daily living including ambulation and functional mobility. Balance impairments have also been proven to have a direct correlation to sport related injuries and declines in overall athletic performance. Since adequate balance is instrumental in sport and function, deficits must be addressed by appropriate treatment modalities to prevent injury and maintain or improve balance. For several years, non-elastic tapes have been frequently used to treat and prevent ankle injuries in athletes and thus restore normal balance capabilities during athletic competition. These types of non-elastic tape are used to provide stability to the joint without compromising normal joint mechanics. They may deliver a strong adhesion force leading to restraint of a body segment but may also cause skin discomfort. However, white athletic tape loses its effectiveness to prevent inversion ankle sprains after 10 minutes of use. While athletic tape is primarily utilized for structural support, Kinesio Tex tape® (KT) was created to provide therapeutic benefits while allowing support and stability to muscles and joints without restricting the body's range of motion. The elastic, acrylic adhesive tape differs from regular white athletic tape because of the wave-like grain design on the adhesive surface of KT. The specialized grain and elasticity of the tape provides a tensile force to the skin and is purported to lift the fascia and soft tissue allowing mobility while providing therapeutic benefits. KT is air permeable and water resistant, allowing it to stay in place for three to five days secondary to its ability to resist moisture without affecting the adhesive quality of the tape. The comfort and freedom of motion after application are unique KT characteristics that athletes value. Numerous beneficial effects have been suggested depending upon KT application technique. The application of KT has been suggested to result in the improvement of muscle contractility by supporting weakened muscles; decrease inflammation and pain by increasing lymphatic and blood flow; increase joint range of motion by adjusting misalignment of muscle fibers, myofascia and joints. Improving circulation and increasing proprioception using KT have also been suggested. To attempt to enhance or facilitate a muscle contraction, KT is applied from muscle origin to insertion with stronger tension i.e. 25-50% of its original length. On the other hand, to attempt to inhibit or lessen a muscle contraction KT is applied from the muscle insertion to origin with weaker tension i.e. 15-25% of its original length.

The possible effect of KT on muscle strength has been investigated by numerous researchers that have theorized that KT facilitates an immediate increase in muscle strength by generating a concentric pull on the fascia. Vercelli et al analyzed the effect of KT on knee extension using three different application approaches including facilitation taping, inhibition taping, and sham taping. None of the three conditions showed an immediate increase or decrease in strength in subjects, when compared to a baseline measure obtained using an isokinetic dynamometer. Similar to Vercelli, Fu and his colleagues applied KT to the quadriceps of healthy athletes and assessed strength also using an isokinetic dynamometer. Strength was assessed immediately following application as well as after a 12-hour period. There were no significant differences immediately after the KT application and when tested 12-hours following application. The inconsistent application and tension applied to the tape may be responsible for the lack of significant findings in the previously presented research.

Lins et al measured balance, using a computerized baropodometer, and also failed to note significant differences after the application of KT to the anterior thigh. However, they may have applied the KT to muscle groups that did not directly influence balance, as researchers have shown that sensory receptors in the muscles surrounding the ankle joint are the only source of information directly influencing postural sway and balance. Bicici et al studied the effect of KT on balance in basketball players with chronic ankle sprains. They concluded that KT did not improve or inhibit balance or functional performance in a population with a chronic musculoskeletal condition. Their results may have been due to less than optimal application of KT for the desired effect of facilitation, as the KT in their study was applied from distal to proximal, which would cause inhibition instead of facilitation according to Kase.
Nakajima et al. investigated the effects of KT on functional performance in healthy individuals. In their study, KT was also applied on the ankle musculature from insertion to origin; the technique suggested for muscle inhibition. Functional performance measured using vertical jump height and dynamic postural control was assessed at baseline (utilizing the Star Excursion Balance Test), immediately after KT application, and 24 hours after taping. Nakajima et al. concluded that at 24 hours post application KT neither decreased nor increased vertical jump height in healthy non-injured young individuals, but did increase dynamic postural control in females, not the male subjects, however, only in two out of the eight directions tested. Limitations of this study include that the authors did not investigate effects of KT after a longer duration of application, and that they utilized a direction and tension of the taping application suggested for inhibition.

In addition to the discrepancies in the literature on the application and tension procedures, there are gaps in the literature regarding the effects of KT greater than 48 hours after application, as well as its effects on functional performance. As a result, the purpose of the present study is to investigate the immediate and long-term effects of the prescribed application of KT (for facilitation) when applied to the dominant lower extremity on healthy individuals. The hypothesis was that balance and functional performance would improve with the prescribed application of KT versus the sham application.

METHODS

Participants: Seventeen healthy subjects (9 males; 8 females) ranging from 18-35 years of age (mean age 23.3±0.72), volunteered to participate in this study, a sample of convenience. All volunteers were healthy individuals who participated in moderate exercise at least twice per week. Exclusion criteria included: 1) individuals with any major musculoskeletal injuries over the previous six months, 2) health issues that would interfere with a subject's safety during exercise, 3) auditory/vestibular impairments, 4) uncorrected visual problems, 5) active malignancy, 6) active cellulitis or skin infection, 7) open wounds in area of application, and 8) history of deep vein thrombosis. All procedures of the investigation were conducted in accordance with the Helsinki Declaration of 1975. The consent form and the study were approved by the Institutional Review Board of New York Institute of Technology.

Procedures: The participants signed the consent form prior to participation in the study. Participants were randomly assigned to either the control (sham KT without tension) or experimental group (KT with tension) in this double blind repeated measures study. There were four assessment periods for balance and functional ability, beginning with the first day pre- and immediately post- KT application. Measurements were also taken 24, 72, and 120 hours after the application of the KT (at the same time each day). The participant's dominant leg was determined by instructing them to kick a soccer ball; once the dominant leg was determined, it was then taped. Each testing session began with the Biodex balance component followed by the functional performance tests (Four Hop Tests). Participants ceased all exercise during the four-day assessment period. The participants' physiological characteristics are presented in Table 1.

KT Application: KT was applied to the gastrocnemius of the participant's dominant leg, while in the prone position, after completion of all baseline assessments. The KT was cut into a Y-strip leaving two tails at one end in order to disperse tension through both heads of the gastrocnemius musculature. The first tail was anchored with no tension at the fibular head, and the other tail was anchored to the medial condyle of the tibia with no tension. After the anchors were secure, the participant's ankle was maximally dorsiflexed in order to stretch the gastrocnemius. The tape was then stretched to 50% tension as it coursed along the midline of the gastrocnemius to promote muscle activation as stated by Kase. The distal aspect of the tape was anchored to the Achilles tendon ending on the plantar surface of the calcaneus with no tension. The application was applied in the same manner, but with no tension for the control group. All partici-

| Table 1. Subject Characteristics: Control (n = 9) Experimental (n = 8) |
|-----------------|-----------------|-----------------|
| Age (yrs)       | 24.63±5.85      | 22.00±1.58      |
| Weight (kg)     | 70.48±16.45     | 60.44±7.68      |
| Height (cm)     | 168.91±9.09     | 164.24±6.72     |
| Reported as Mean±Standard Deviation |
pants and the measurement team were blinded to their group assignment to increase the validity of the study and protect against the placebo effect. A Certified KT Practitioner completed each tape application in order to maintain consistency throughout the study. (Figure 1)

Balance Testing: Balance testing was conducted using the Balance System SD (Biodex Medical Systems, Shirley, NY). Each participant's age and height was entered into the unit so that normative values could be calculated. The participant then stood barefoot with their dominant foot centered on the balance platform for single-leg testing. The participant's sway while in single-leg stance caused the platform to move and the degrees of motion of the platform was recorded as the participant attempted to balance on the moveable surface. The participant received simultaneous visual feedback of the balance platform's position and its movement by a cursor on a target where center was the optimal neutral position. Participants were instructed to keep the cursor in the middle of the target as they balanced without using their upper extremities for support. The average of two 20-second dynamic trials were performed and recorded for each leg. Balance ability was measured in units of Dynamic Stability Index (DSI) in which a lower index indicated less platform movement and, therefore, better balance. Reliability and validity of the Biodex Balance System has been previously documented by Schmitz et al.21

Hop Testing: Four hop tests comprised the functional performance testing. These included the single hop for distance, triple hop for distance, 6-meter timed hop, and cross-over hop for distance, in sequential order. Participants repeated all four hop tests three times each. The maximum distance or minimum time required to hop a measured distance during each of the three test trials were recorded. To perform the single hop test for distance, participants stood behind the starting line on the leg to be tested and landed on the same leg. The participants were instructed to hop as far as possible. The distance from the starting line to the back of the heel after completing the single hop was measured. The triple hop test was performed beginning by having the participant stand behind the starting line on the leg to be tested and hopping for three consecutive maximum hops on the same leg. The distance from the starting line to the back of the heel after completing the third hop was measured. The 6-m timed hop test consisted of the participant hopping 6-m as quickly as possible. Participants were instructed to perform one-legged hops, as quickly as possible from the starting line to the finish line. An electric stopwatch (Timex Ironman, Waterbury, CT, USA) was used to record the time elapsed. The crossover hop test was performed by the participant standing behind the starting line on the leg to be tested and hopping forward three times in succession while crossing a 15 cm-wide marked strip during each hop. The participant was instructed to hop as far as possible. The distance from the starting line to the heel after completing the third hop, was measured. The best score on each test was used for subsequent data analysis. The test trials were repeated if the participants were unable to complete it or lost their balance as demonstrated by contacting the ground with
the opposite foot. The reliability of this standardized hop-test protocol has been demonstrated in previous research by Reid et al.\textsuperscript{23}

**STATISTICAL ANALYSIS**

Statistical analyses were performed utilizing SPSS for Windows (version 22.0, Chicago, Ill.), using a multifactor repeated measures design. Repeated measures ANOVA's were performed for each individual dependent variable. The dependent variables were the four hop tests and the DSI score from the balance test, with time as the repeated factor. In the event of significant interaction and/or main effects, appropriate post hoc analysis was used. The assumption of sphericity was tested using Mauchly's test, in the event that sphericity was violated a Greenhouse-Geisser correction factor was applied. A priori sample size calculations revealed that eight subjects were required in each group in order to detect observed differences at a power of 80%. Statistical significance was set at $p < 0.05$.

**RESULTS**

Descriptive characteristics of the subjects are presented in Table 1. The mean and standard deviation scores for each of the balance and each of the hop tests for both the KT and sham groups are presented in Table 2. There were no significant differences for main and interaction effects between KT and sham groups for the balance (DSI scores) and the hop tests. (Table 3)

**DISCUSSION**

The aim of the present study was to bridge the gap in knowledge and clarify discrepancies in the literature regarding the effects of KT on functional performance and balance, by providing 120 hours of wear time and the utilization of a prescribed KT application technique. However, the findings of the present study indicated that the application of KT when applied from origin to insertion of the gastrocnemius with 50% tension compared to sham application did not improve balance or functional performance. These results compare to those from a recent study by Nunes et al\textsuperscript{22} who applied KT to healthy individuals in the same fashion as the present study and also failed to find any significant improvements in balance. They assessed balance during a single testing session that took place anywhere from 48 hours to one week following application of KT. Failure to find statistically significant differences in performance or balance in the present study as well as Nunes' may be attributed to use of a healthy subject population. Since all participants were healthy active individuals who took part in activities that challenged their balance on a daily basis, their balance may not have been able to significantly improve. Lins et al\textsuperscript{17}

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### Table 2. Scores of the Balance and Functional Performance Tests, reported as Mean ± Standard Deviation

<table>
<thead>
<tr>
<th>Crossover Hop (cm)</th>
<th>Control</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td>376.55±21.33</td>
<td>390.67±88.32</td>
</tr>
<tr>
<td>Post</td>
<td>387.63±115.85</td>
<td>409.17±95.89</td>
</tr>
<tr>
<td>24 Hour</td>
<td>397.79±100.46</td>
<td>403.77±85.68</td>
</tr>
<tr>
<td>72 Hour</td>
<td>403.38±93.31</td>
<td>408.20±86.50</td>
</tr>
<tr>
<td>120 Hour</td>
<td>353.85±175.95</td>
<td>347.14±149.45</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Triple Hop (cm)</th>
<th>Control</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td>402.14±116.15</td>
<td>425.57±118.52</td>
</tr>
<tr>
<td>Post</td>
<td>427.80±124.01</td>
<td>425.41±105.20</td>
</tr>
<tr>
<td>24 Hour</td>
<td>446.94±105.68</td>
<td>438.56±99.77</td>
</tr>
<tr>
<td>72 Hour</td>
<td>446.55±109.48</td>
<td>440.28±97.13</td>
</tr>
<tr>
<td>120 Hour</td>
<td>363.43±182.96</td>
<td>371.77±161.29</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>6-Meter Hop (seconds)</th>
<th>Control</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td>2.23±.51</td>
<td>2.08±.46</td>
</tr>
<tr>
<td>Post</td>
<td>2.09±.52</td>
<td>2.00±.45</td>
</tr>
<tr>
<td>24 Hour</td>
<td>2.17±.47</td>
<td>2.15±.37</td>
</tr>
<tr>
<td>72 Hour</td>
<td>1.89±.39</td>
<td>1.87±.50</td>
</tr>
<tr>
<td>120 Hour</td>
<td>1.88±.85</td>
<td>2.03±.93</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Single Hop (cm)</th>
<th>Control</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td>132.53±36.91</td>
<td>129.71±36.51</td>
</tr>
<tr>
<td>Post</td>
<td>135.05±38.20</td>
<td>136.12±29.64</td>
</tr>
<tr>
<td>24 Hour</td>
<td>133.91±35.51</td>
<td>138.56±27.68</td>
</tr>
<tr>
<td>72 Hour</td>
<td>138.81±34.02</td>
<td>135.83±28.71</td>
</tr>
<tr>
<td>120 Hour</td>
<td>109.29±56.94</td>
<td>111.42±47.72</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DSI</th>
<th>Control</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td>1.79±.37</td>
<td>1.55±.54</td>
</tr>
<tr>
<td>Post</td>
<td>1.56±.54</td>
<td>1.56±.64</td>
</tr>
<tr>
<td>24 Hour</td>
<td>1.59±.81</td>
<td>1.34±.44</td>
</tr>
<tr>
<td>72 Hour</td>
<td>1.47±.58</td>
<td>1.49±.50</td>
</tr>
<tr>
<td>120 Hour</td>
<td>1.49±.66</td>
<td>1.39±.39</td>
</tr>
</tbody>
</table>

**Table 3. Results of 2X5 Repeated Measures ANOVA's for Balance and Functional Performance**

<table>
<thead>
<tr>
<th>Test</th>
<th>Group</th>
<th>Time</th>
<th>Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crossover</td>
<td>P=0.85</td>
<td>P=0.29</td>
<td>P=0.99</td>
</tr>
<tr>
<td>Triple Hop</td>
<td>P=0.95</td>
<td>P=0.13</td>
<td>P=0.82</td>
</tr>
<tr>
<td>6-Meter Hop</td>
<td>P=0.91</td>
<td>P=0.12</td>
<td>P=0.57</td>
</tr>
<tr>
<td>Single Hop</td>
<td>P=0.11</td>
<td>P=0.84</td>
<td>P=0.95</td>
</tr>
<tr>
<td>DSI</td>
<td>P=0.65</td>
<td>P=0.32</td>
<td>P=0.70</td>
</tr>
</tbody>
</table>

Group = Effect of Control vs. Experimental
Time = Effect of Time (Pre, Post, 24, 72 and 120 Hours Post)
Interaction = Interaction Effect between Group and Time
All results were not significant
assessed the effects of KT on balance and functional performance using taping to assist in activation of the anterior thigh musculature of healthy subjects. Although Lins used the prescribed KT application for muscle activation, they also failed to find a significant difference in outcome measures. The quadriceps and gastrocnemius-soleus complex have both been proven to play a significant role in jumping performance. In addition, the gastrocnemius-soleus complex provides ankle stability during balance, which led the authors of the current study to tape the gastrocnemius-soleus complex. Although the same outcome measures and prescribed KT muscle activation technique as Lins et al were used in the current study, no significant improvements in any variables were demonstrated in healthy subjects.

Nakajima et al investigated the effects of KT on balance using a technique to treat lateral ankle sprains as depicted in Kenzo Kase’s KT manual. In contrast to Bicici et al, Nakajima and colleagues used a variation of the inversion ankle sprain technique and subjects were all healthy individuals. Researchers applied three different strips of KT with 140% tension to gastrocnemius, anterior tibialis and peroneals from distal to proximal. The investigators found no significant improvements in vertical jump or dynamic posture both immediately and 24 hours following application of KT. Failure to find significant differences in the subjects in Nakajima’s study might be related to application technique, tension of KT, as well as the subject population. Nakajima et al applied excessive tension, which neither inhibits nor activates but rather compresses the muscle; therefore, it is not desirable when aiming to improve balance. Nonetheless, due to variations in the current findings and previous findings, the authors of the current study acknowledge the need to evaluate effects of KT on subjects with musculoskeletal impairments.

The main limitation of the present study was the use of a healthy population because KT is typically prescribed for individuals with musculoskeletal injury or impairment. Another limitation may be that the KT was only applied to the gastrocnemius-soleus complex; thus, future studies could also apply KT to the quadriceps and peroneal musculature and study balance and performance.

CONCLUSION

The results of the present study did not show any significant difference in balance and functional performance when KT was applied to the gastrocnemius with or without tension in healthy individuals. Based on the results of this study, KT wearing time or application technique may not be reasons for lack of significant findings in balance or functional performance improvements, rather the reason may be that KT should be prescribed for patients with musculoskeletal impairments, as originally suggested by the creators of KT.

REFERENCES


ABSTRACT

Background and Purpose: Posterior shoulder tightness has been associated with numerous shoulder disorders. Methods to increase posterior shoulder mobility may be beneficial. The purpose of this case report is to report the outcomes of a subject with posterior shoulder tightness treated with dry needling as a primary intervention strategy.

Case description: The subject was a 46-year-old man who was referred to physical therapy with primary symptoms of shoulder pain and loss of motion consistent with subacromial impingement syndrome. Clinical findings upon examination revealed glenohumeral internal rotation and horizontal adduction losses of motion and reproduction of pain symptoms upon palpation of the infraspinatus, teres minor, and posterior deltoid. A single treatment of trigger point dry needling was used to decrease pain and improve range of motion.

Outcomes: Following the intervention, clinically meaningful improvements were seen in pain and shoulder range of motion.

Discussion: This case report describes the use of trigger point dry needling in the treatment of a subject with posterior shoulder tightness. The immediate improvement seen in this subject following the dry needling to the infraspinatus, teres minor, and posterior deltoid muscles suggests that muscles may be a significant source of pain and range of motion limitation in this condition.

Level of Evidence: Level 4

Keywords: Dry needling, myofascial trigger point, shoulder pain, subacromial impingement syndrome.
BACKGROUND AND PURPOSE

Posterior shoulder tightness (PST) has been suggested to be a causative or perpetuating factor in impingement syndrome, labral lesions, and rotator cuff tears encountered in clinical rehabilitation and sport activities. The mechanism by which PST is associated with abnormal glenohumeral biomechanics has been elucidated in both cadaveric and clinical studies. In cadaveric studies, selective tightening of the posterior capsule by plication has been shown to increase anterior and superior translation of the humeral head during flexion, cross-body adduction and external rotation, and posterior translation during external rotation at 90° of abduction, with markedly decrease internal rotation. In clinical studies, PST have been demonstrated in overhead athletes with internal impingement and in subjects with secondary impingement and frozen shoulder.

Typically, PST is identified by measuring the range of motion (ROM) of glenohumeral internal rotation (IR) and horizontal adduction (HA). The decreased HA and IR ROM is thought to be a multifactorial condition that involves sport-specific bony adaptations in the overhead athlete (increased humeral retroversion), tightness of dynamic restraints (infraspinatus, teres minor, and posterior deltoid) and/or posterior capsule contracture. These potential mechanisms have provided rationales for treatment options. Stretching, joint mobilization techniques, and/or massage are commonly used to treat IR and HA ROM loss due to muscular or capsular limitation and related symptoms.

Physical therapy treatment interventions focusing on posterior shoulder stretching have resulted in a decrease in the loss of IR and HA ROM, and a marked improvement in pain in several studies. Techniques for stretching the posterior shoulder include the sleeper-stretch and the cross-body stretch, passively performed by the therapist or by the patient. Glenohumeral joint mobilization techniques (dorsal glide mobilizations in the scapular plane; grade III and IV in the Maitland classification) have been suggested to decrease stiffness of the posterior glenohumeral joint capsule and to increase IR ROM. A protocol that includes posterior joint mobilizations in combination with the cross-body stretch appears to be an effective intervention to increase glenohumeral IR ROM and decrease posterior shoulder tightness. The increase in ROM in asymptomatic individuals also suggests that stretching and joint mobilization may be an effective tool for the prevention of disorders related to PST.

Soft tissue massage of the infraspinatus, posterior deltoid, and teres minor muscles is often included in rehabilitation of individuals with PST in order to increase glenohumeral internal rotation ROM deficit. Similarly, muscle energy techniques have been shown to provide immediate improvements in both glenohumeral HA and IR ROM in asymptomatic individuals, further confirming the muscle contribution in the genesis of PST. However, the optimal treatment for correcting PST remains unknown and it is also not known whether or not a home-based course of treatment is as effective as one that is administered by a clinician.

Dry needling (DN) is a skilled intervention performed by physical therapists as part of clinical practice in combination with other physical therapy interventions, such as mobilization, manipulation, soft tissue massage, and exercises. DN uses a solid filiform needle to penetrate the skin to treat muscles, ligaments, tendons, subcutaneous fascia, scar tissue, peripheral nerves, and neurovascular bundles for the management of a variety of neuromusculoskeletal pain syndromes. DN is not limited to myofascial intervention, although this case report’s DN intervention was focused on treating myofascial trigger points (MTrPs) in the local tissue. DN techniques are proposed to treat a host of pathological conditions, such as neck pain, chronic lateral hip and thigh pain, and chronic low back pain. MTrPs have been studied extensively over the years as sources of pain, and the literature suggests a MTrP is identified clinically by palpation of a tender nodule in a taut band of muscle and subjective report of pain during tender spot palpation. MTrPs are divided into active and latent MTrPs, both of which generate dysfunction. However, the symptoms differ because active MTrPs may cause spontaneous pain, while latent MTrPs elicit pain when stimulated, for example, with digital pressure. Although latent MTrPs are not spontaneously pain-
ful, they do contribute to nociception, muscles weakness, muscle fatigue, alteration of muscle activation patterns, and ROM restriction, therefore they need to be included in the treatment plan.\textsuperscript{31}

Although the pathophysiology of MTrPs remains relatively unclear and is not universally accepted, DN is used in clinical practice to 1) quickly reduce local, referred, and/or remote pain, 2) remove peripheral sources of persistent nociceptive input, 3) improve ROM and muscle activation patterns, 4) relax the taut band, 5) reduce the concentration of numerous nociceptive, inflammatory, and immune system related chemicals, 6) reduce peripheral and central sensitization.\textsuperscript{25,32,33,34} DN of MTrP in the infraspinatus muscle has been demonstrated to be an effective intervention for subjects with chronic shoulder pain and IR ROM deficits.\textsuperscript{35} A case series by Osborne and Gatt showed improved shoulder ROM, function, and pain in four volleyball players after DN of the infraspinatus and teres minor muscles.\textsuperscript{36} In a case series by Ingber, three subjects with shoulder pain were treated with DN and stretching of the subscapularis muscle.\textsuperscript{37} They achieved pain-free ROM at the end of their treatment, which persisted at a two-year follow-up. In a case report, Clewely described the clinical reasoning and outcomes leading to the use of DN to the upper trapezius, levator scapula, deltoit, and infraspinatus muscles as part of a plan of care in a subject with adhesive capsulitis.\textsuperscript{38} The outcomes showed significant improvement in shoulder ROM, pain, and function, especially after the addition of DN.

However, there are no studies in the current literature supporting the use of DN as an effective intervention for loss of shoulder ROM and pain associated with PST. The purpose of this case report was to describe the acute effects of DN as a primary treatment intervention in a subject with PST. The subject featured in this case report gave written informed consent to participate in the study and was informed that the data concerning the case report would be submitted for publication.

**CASE DESCRIPTION**

The subject in this study was a 46-year-old right-handed male dance instructor, who was referred to physical therapy by his orthopaedic surgeon, with a diagnosis of subacromial impingement syndrome. He had a three-month history of right shoulder pain and stiffness, of insidious onset. There were no reports of trauma to the neck or shoulder, and he had no previous history of neck or shoulder symptoms.

His general health was good and absent of signs suggestive of non-musculoskeletal pathology. Anti-inflammatory medication had been previously prescribed for this condition, but the subject found no relief with this intervention. The subject described two areas of pain. The first area (P1, Figure 1) was located over the anterior aspect of the right shoulder. Using an 11-point Numeric Pain Rating Scale (NPRS), with 0 as no pain and 10 as worst pain imaginable, his pain intensity in this location was rated as 7/10. The NPRS has been demonstrated to be a valid and reliable tool for subjects with shoulder pain.\textsuperscript{39} The subject described the pain as a sharp burning sensation provoked while maintaining a typical position of his working activity, with the right arm slightly in IR at 90° of abduction (Figure 2). Onset of pain was immediate with this posture, and reduction of 

![Figure 1. Pain diagram. P1 and P2 indicate two distinct areas of perceived pain by the subject, P1 = primary pain area, P2 = secondary pain area.](image-url)
pain occurred immediately after taking his arm out of this position.

The second area of pain (P2, Figure 1) was defined as an area along the medial border of the right scapula. The intensity of pain on the NPRS was rated as 6/10, with the same aggravating/easing factors. However, in this region the pain increased only after a prolonged position of shoulder abduction. Pain affected his work and required him to take frequent breaks to reduce his pain symptoms. His goal was to reduce pain and stiffness to improve his ability to work. The outcomes measured at baseline and immediately after the intervention were pain intensity, shoulder passive ROM, and provocation tests.

EXAMINATION/EVALUATION
The subject’s cervicothoracic spine was examined as a possible source of shoulder pain. A detailed exam in the sitting position that included observation, bony and soft tissue palpation, and assessment of active and passive cervical ROM with overpressure was performed. Additionally, the upper limb tension test A, the Spurling test, and cervical distraction test were performed to rule out cervical nerve root pathology. None of the tests elicited pain in the shoulder or neck. The observation and palpation did not show any differences in shoulder muscle trophism or significant postural asymmetries.

The Hawkins-Kennedy, painful arc sign, and infraspinatus muscle strength tests were performed as a test-item cluster for subacromial impingement syndrome. The post-test probability for this cluster that the patient will exhibit rotator cuff tendinopathy and/or subacromial impingement syndrome of the three above tests is 95.5% if all three are positive, and 91.0% if two of three are positive. Pain during the provocative tests was rated using NPRS. The Hawkins-Kennedy and painful arc of motion tests elicited 5/10 pain in the P1 region. Infraspinatus muscle testing did not show pain or weakness.

A Tracker Freedom® Wireless Dual Inclinometer (JTECH Medical, Midvale, UT) was used to measure bilateral passive glenohumeral IR, HA, external rotation, and abduction ROM. This device provides real-time digital reading of angles through the pressure of a pedal board, allowing the examiner to not change the location to look at the tool as it is using an inclinometer or a standard goniometer, thereby reducing a possible source of error. Each measurement was performed twice with a 10 second rest between repetitions to improve reliability, and averaged for further analysis. This procedure, using a wireless inclinometer to measure ROM of the shoulder, is reported to be reliable if carried out by the same examiner, with an intraclass correlation coefficient of 0.96 with a minimal detectable change (MDC) of 6.9° for IR, 0.96 with a MDC of 4.8° for external rotation, 0.92 with a MDC of 6.4° for abduction, and 0.85 with a MDC of 9.5° for HA.

For assessment of shoulder IR, the subject was positioned in the supine position with the shoulder at 90° of abduction in the plane of the scapula (10-15° anterior to the coronal plane) and the elbow flexed to 90°. The inclinometer was placed on the dorsal surface of distal forearm. The examiner passively internally rotated the glenohumeral joint, controlling scapular movement by palpation of the coracoid process with the thumb and the spine of the scapula with the finger, to feel for motion, and minimize scapulothoracic contribution or compensatory movement that occurs at the end of IR motion. When the scapula started to move into protraction and/or anterior tilt, the measurement was taken (Figure 3). This method of stabilization showed the optimal amount of scapular stabilization and also showed both high inter-rater and intra-rater reliability.

For measurement of external rotation, the subject was positioned in the supine position with the shoulder abducted at 90° in the scapular plane and the elbow flexed at 90°. The inclinometer was placed on the dor-
sal surface of distal forearm. The scapula was stabilized by contact with the bed. The examiner passively externally rotated the humerus and the measurement was taken when resistance to any further motion was encountered and attempts to overcome the resistance caused a posterior tilt or retraction of the scapula. For measurement of glenohumeral abduction, the subject was in the seated position with the elbow flexed at 90°. The inclinometer was placed on the lateral surface of distal humerus. The examiner passively abducted the glenohumeral joint stabilizing the scapula and the measurement was taken when resistance to any further motion was encountered. The HA was measured with the subject in the side-lying position. The subject laid with the trunk aligned perpendicular to the treatment table with hips and knees flexed to 45°. The inclinometer was placed on the lateral surface of distal humerus. The lateral border of the scapula was manually stabilized in a retracted position. From a position of 90° of humeral abduction and neutral humeral rotation, the examiner passively lowered the arm into horizontal adduction by gripping the participant’s forearm just distal to the humeral epicondyles (Figure 4). The arm was lowered until the humeral horizontal adduction end range was reached (Figure 5). Table 1 displays shoulder ROM measurements at initial exam. The differences in the pre-intervention condition observed in the glenohumeral IR and HA ROM between the right and the left shoulder were 24° and 8°, respectively, which could be considered clinically meaningful differences.

Following subjective history and physical examination, MTrPs in the infraspinatus, teres minor, and

<table>
<thead>
<tr>
<th>Measures</th>
<th>Right shoulder</th>
<th>Left shoulder</th>
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<tbody>
<tr>
<td>Internal rotation</td>
<td>44°</td>
<td>68°</td>
</tr>
<tr>
<td>External rotation</td>
<td>74°</td>
<td>71°</td>
</tr>
<tr>
<td>Abduction</td>
<td>90°</td>
<td>96°</td>
</tr>
<tr>
<td>Horizontal adduction</td>
<td>10°</td>
<td>18°</td>
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posterior deltoid muscles were suspected as the underlying pathology. According to the literature, the ability to definitively ascertain the exact location of a MTrP is questionable, and examiner experience plays a positive role in determining the presence of a MTrP.\textsuperscript{30,45,46} Identification of a tender nodule in a taut band of muscle along with reproduction of the subject's subjective report of pain is the most clinically accurate way to recognize the presence of a MTrP.\textsuperscript{47}


**DIAGNOSIS**

Subject reports of anterior pain, a positive Hawkins-Kennedy test, and a positive painful arc sign were consistent with diagnosis of subacromial impingement syndrome. Decreased glenohumeral IR and HA ROM identified the presence of PST.\textsuperscript{7}

**INTERVENTION**

Risks and potential complications were advised and written consent was obtained outlining common and serious adverse events associated with DN interventions. Common complications include bruising, vasovagal response, bleeding, and muscle soreness. More serious (but rare) complications include infection, broken needle, and pneumothorax.\textsuperscript{48} There were no reported contraindications to the use of DN. Intervention was performed by a physical therapist with advanced training in DN.

DN was performed to the infraspinatus, teres minor, and posterior deltoid muscles at the areas determined by deep palpation as a possible locations of the MTrPs. The needles used for the treatment of the subject in this case report were solid monofilament Seirin J-type sterile needles, No. 8 (0.30 diameter) x 40 mm. in length. After skin inspection and cleaning with 70% isopropyl alcohol, the needle was inserted through the muscle belly in the tender nodule in the taught band. Each needle was held in the therapist’s dominant hand for application of and manipulation of the needle within the tissue. The DN technique utilized ten fast-in/out movements in a cone pattern to attempt to target as many sensitive loci as possible within the tender nodule in the taut band of muscle. As soon as the needle was pulled out of the skin, the needle insertion site was compressed firmly for hemostasis for up 30 seconds and the needle discarded into a sharps container.

For the infraspinatus muscle, the subject was positioned prone with the arm slightly abducted. DN of the infraspinatus muscle was performed using flat palpation to identify the location of the tender nodule in the taught band of muscle located one-third the distance from the scapular spine. The needle was inserted to a depth of 100 mm perpendicularly through the skin directly into the taught band towards the scapula. For the teres minor muscle, the subject was positioned prone with the upper arm abducted to 90°. A tender nodule was located, using flat palpation, in the middle of the muscle belly and the needle was inserted to a depth of 100 mm two fingerbreadths distal to the glenohumeral joint and directed to the lateral border of the scapula. For the posterior deltoid muscle, the subject was positioned prone with the upper arm slightly abducted. A tender nodule was located, using pincer palpation, in the middle of the muscle belly. The needle was inserted to a depth of 200 mm through the muscle and tangential to the humerus.

**OUTCOMES**

A clinically meaningful improvement was demonstrated in post-treatment shoulder pain intensity and ROM immediately following a single application of DN. The results of these outcome measures are shown in Table 2. Pain decreased from 7/10 to 2/10 in P1 and from 6/10 to 2/10 in P2 on the NPRS with this provocative position. Pain intensity decreased from 5/10 to 1/10 and from 5/10 to 0/10 during the performance of Hawkins-Kennedy and painful arc sign tests, respectively. For subjects with shoulder pain, the minimal clinically important difference for the NPRS has been reported to be 2.17.\textsuperscript{49} IR ROM improved from 44° to 62°, HA from 10° to 29°, external rotation from 74° to 76°, and abduction from 90° to 96°. Changes in IR and HA ROM were greater than the MDC.\textsuperscript{43}

**DISCUSSION**

The purpose of this case report was to describe the efficacy of DN for a subject with PST. The subject demonstrated improvements in pain and gleno-
humeral IR and HA ROM. PST is often assessed by quantifying glenohumeral IR. In this study, IR ROM increased 18° immediately after DN. Similar to previous studies and clinical experience, this finding suggests that tightness of infraspinatus, teres minor and posterior deltoid muscles may contribute to PST and loss of glenohumeral IR ROM.

There is no consensus about the optimal position and measurement technique to quantify PST, but according to Kolber et al there is a need to isolate glenohumeral HA by restricting scapular protraction while performing the test. A 19° improvement was observed after DN. Tyler et al. demonstrated a similar improvement in HA (27° ± 19°) after seven-week mobilization of the posterior shoulder, scapular-stabilization strengthening exercises and stretching. Change in HA ROM in the present study is far better than the one previously reported by Laudner et al. showing a 3° marginal improvement immediately after two repetitions of 30 seconds of the sleeper-stretch, performed by the therapist.

Although posterior capsular stiffness has been described as a primary factor contributing to PST, these results suggest that glenohumeral movement deficit and pain associated with this clinical issue may also be influenced by the posterolateral shoulder muscles. Palpable taught bands present in the infraspinatus, teres minor, and posterior deltoid muscles and reported pain reproduction in the shoulder region led to the clinical decision to use DN as the intervention. Although the etiology of PST is multifactorial, it is possible that neuromotor abnormalities, such as muscle weakness of the involved painful muscle and altered motor activation patterns, contribute to pain and ROM impairments, including the development of MTrPs in the shoulder muscles.

Results of preliminary investigations suggest that DN both modulates pain and improves ROM. Analgesia may occur via the gate control theory occurring during needle insertion and/or via stimulation of the endogenous anti-nociceptive modulation system. Restricted ROM may be observed secondary to a contracted taut band, however, is unknown exactly why the ROM increase occurred. Improvement in the ROM observed in the subject after the DN might have been due to a decrease in pain, which allowed an increase in movement.

<table>
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<tr>
<th>Table 2. Outcome measures</th>
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<td>Outcome measures</td>
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<tr>
<td>Pain in provocative posture at P1 (NPRS)</td>
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<tr>
<td>Pain in provocative posture at P2 (NPRS)</td>
</tr>
<tr>
<td>Internal rotation</td>
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<tr>
<td>External rotation</td>
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<tr>
<td>Abduction</td>
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<tr>
<td>Horizontal adduction</td>
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<td>Hawkins-Kennedy test (NPRS)</td>
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<tr>
<td>Painful arc sign (NPRS)</td>
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</table>

P1=primary pain presentation, P2=secondary pain presentation, NRPS=Numerical pain rating scale.

Note: NPRS scores are reported during a provocative posture and the performance of special tests.
The subject tolerated the DN intervention very well with no side effects reported following treatment. The subject reported minimal muscle soreness at the area of needle penetration that lasted approximately three hours following treatment.

The results of this case report showed a reduction of pain in the scapular region after the treatment of the glenohumeral muscles. The referred pain in this region by one of the treated muscles has not been described in literature. The painful symptom could have been caused by an overload of the stabilizing muscles of the scapula (trapezius and rhomboids). Several authors have highlighted how limitations of the glenohumeral ROM can alter the scapulothoracic rhythm. It is possible that the DN intervention decreased the mechanical load on the scapular muscles by improving glenohumeral ROM, thus reducing the pain.

This case report uses only a single subject, as is typical of a case report research. This is an inherent limitation to a case report, offering only results that relate to this subject that cannot be generalized. Larger randomized control studies looking at DN interventions need to be performed in order to fully assess the effectiveness of DN as a primary intervention for PST. Studies with additional assessment periods designed to investigate immediate versus longer term benefits of DN need to be conducted. Further research is recommended to determine if DN is clinically beneficial independent of other therapeutic interventions such as general or specific exercises targeting the affected musculature, or other manual therapy techniques such as mobilization or soft tissue massage.

CONCLUSION

This case report described the treatment of a subject with PST using DN. DN was tolerated well by this subject, demonstrating clinically meaningful improvements in shoulder ROM and pain, without adverse effects. The findings from this case report indicate that DN may be effective in the treatment of PST when the presentation includes stiffness of posterolateral shoulder muscles and the presence of clinically relevant MTrPs, identified as a primary source of pain and ROM restriction. Further research is recommended to determine the functional outcomes of DN for PST, as well as to determine long-term outcomes, before conclusions can be made regarding the effectiveness of this approach.

REFERENCES


ABSTRACT

Context: Anterior cruciate ligament (ACL) reconstruction is frequently performed to allow individuals to return to their pre-injury levels of sports participation, however, return to pre-injury level of sport is poor and re-injury rates are unacceptably high. Re-injury is likely associated with the timeframe and guidelines for return to sport (RTS). It is imperative for clinicians to recognize risk factors for re-injury and to ensure that modifiable risk factors are addressed prior to RTS. The purpose of this commentary is to summarize the current literature on the outcomes following return to sport after ACL reconstruction and to outline the biologic and patient-specific factors that should be considered when counseling an athlete on their progression through rehabilitation.

Evidence Acquisition: A comprehensive literature search was performed to identify RTS criteria and RTS rates after ACL reconstruction with consideration paid to graft healing, anatomic reconstruction, and risk factors for re-injury and revision. Results were screened for relevant original research articles and review articles, from which results were summarized.

Study Design: Clinical Review of the Literature

Results: Variable RTS rates are presented in the literature due to variable definitions of RTS ranging from a high threshold (return to competition) to low threshold (physician clearance for return to play). Re-injury and contralateral injury rates are greater than the risk for primary ACL injury, which may be related to insufficient RTS guidelines based on time from surgery, which do not allow for proper healing or resolution of post-operative impairments and elimination of risk factors associated with both primary and secondary ACL injuries.

Conclusions: RTS rates to pre-injury level of activity after ACLR are poor and the risk for graft injury or contralateral injury requiring an additional surgery is substantial. Resolving impairments while eliminating movement patterns associated with injury and allowing sufficient time for graft healing likely gives the athlete the best chance to RTS without further injury. Additional research is needed to identify objective imaging and functional testing criteria to improve clinical decision making for RTS after ACLR.

Level of Evidence: Level 5

Key Words: Anterior cruciate ligament, reconstruction, return to sport, rehabilitation, injury prevention

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INTRODUCTION
Return to sport participation after anterior cruciate ligament (ACL) reconstruction (ACLR) is an important measure in determining successful outcomes and is an expectation of highly active individuals. The decision to clear a patient to progress rehabilitation to include demanding activities, such as cutting and plyometrics, and eventually return to sport must balance the wishes and desires of the patient with the current and future health of the knee joint. Conventional clinical advice is for athletes to return pre-injury sports participation between four and six months post-operatively, however, time-based recommendations are based in theory and often do not accurately reflect patient capabilities. In a recent systematic review, 158 studies out of 264 (60%) utilized time after surgery as a criteria to return to sport. Of those 158, 84 (53%) determined that six months was the earliest that patients were allowed to return to sport. Only 35 studies (13%) used objective criteria to determine RTS readiness. As this literature review shows, time after surgery is the most common criteria used to determine readiness to return to sport. At present, no set of criterion based measures have been adequately studied to determine whether or not they are appropriate for ensuring successful return to sport with the smallest possible chance of re-injury or contralateral knee injury.

The purpose of this commentary is to summarize the current literature on the outcomes following return to sport after ACL reconstruction and to outline the biologic and patient-specific factors that should be considered when counseling an athlete on their progression through rehabilitation. The factors addressed are not an all-inclusive list but the biologic factors are used to provide safe guidance based on time after surgery and the patient-specific factors are modifiable ones that guide the regular evaluation of motor control through the rehabilitation process.

DEFINING RETURN TO SPORT
When discussing return to sport after ACLR, a clear definition is needed due to the many contextual factors that surround sport. Return to sport has been operationally defined as participation in regular season competition (or pre-season competition) or physician clearance for return to training and match play. Feller and Webster advocate clarity when discussing pre-injury sport and pre-operative sport, as pre-operative sport participation can be influenced in chronic ACL deficiency; and for distinguishing between training and competition, with respect to the level of competition and competency of participation.

Careful attention should be paid to the reasons that individuals do not return to pre-injury participation with long term follow-up, as lifestyle changes and fear of re-injury may prevent return to pre-injury status as opposed to inadequate knee joint structure and function. The authors advocate for classifying successful return to sport status to be defined based on returning to the same type, intensity and frequency of activity as at the time of injury, and having at least the same Marx Activity Rating Scale scores. Cameron et al reported that men with a history of knee injuries have a mean Marx score of 12.58 and men with no history of knee injuries have a mean score of 12.17. Women with a history of knee injuries have a mean Marx score of 12.39 and women with no history of knee injuries have a mean score of 10.94. Comparing the frequency of running, cutting, twisting, and jumping and the above referenced Marx scores before injury and after surgery reduces the chance of incorrectly identifying individuals as having successfully returned to sport by decreasing the demands of the sport itself (i.e. the individual may have returned to playing soccer, but does not perform the demands of sport as often). Furthermore, reasons for decline in sports activity and participation after surgery should be thoroughly documented, and the individual's satisfaction with their activity level should be considered. This definition of return to sport provides a more comprehensive representation of activity level than does the Tegner Activity Scale, which has noted flaws in the measurement of activity level towards the higher end of the scale.

CURRENT RETURN TO SPORT LITERATURE
In a study that followed 503 individuals for 12 months after ACLR, only one-third of individuals had attempted full competition, one-third were in training or modified competition, and one-third had not attempted training or return to sport. Younger athletes, males, and those athletes who participated in seasonal team sports were more likely to attempt...
return to sport by one year after ACL reconstruction. In further follow-up at an average of 3.5 years after ACLR, return to sport rates improved to 82% for individuals attempting to return to some form of sports, however, only two-thirds of individuals returned to their pre-injury level of sport participation, and less than half returned to competitive sports. The rate of return to pre-injury sports is lower (61.9%) for participants in cutting and pivoting sports (Level 1) than for individuals who participated in sports (77.8%) with less challenging lateral movements (Level 2).

Return to sport rates have been investigated for specific Level 1 sports, defined as sports which challenge knee joint stability in the transverse plane involving jumping, cutting, and pivoting such as football, soccer, or basketball. A wide range of success rates for specific sports exists in the literature: 63% - 69% for American football (high school, college, NFL), 78% in the National Basketball Association, and 72% - 89% in soccer. Age is a significant factor in whether an athlete will return to sport. More than 70% of individuals under the age of 25 were able to return to either strenuous or very strenuous sports (cutting, pivoting, and/or lateral movements), but only between 43% and 57% were able to resume pre-injury activity levels. The risk of subsequent injury to either knee was 17% for patients younger than 18 years of age, 7% for patients 18 to 25 years of age, and 4% for patients older than 25 years of age. Regardless of the actual short-term rate of return to sport, participation declines with longer duration post-operative follow-up, which likely follows the natural history of an individual’s athletic career.

### Biological and Surgical Considerations for Return to Sport Decisions

The selection of either autograft or allograft tissue for ACLR is usually based on patient and surgeon preference, patient age, activity level, physical requirements, timeline for return to play, as well as comorbidities and concomitant injuries. When making the return to sports decision, a primary factor to consider is prevention of recurrent injury by ensuring that the graft has healed appropriately and is capable of withstanding the demands placed upon it. Following ACL reconstruction, the graft undergoes a process of “ligamentization” whereby the tissue transitions from its natural state to a structure that approximates the native ACL (but does not achieve the exact ultra-structure of the native ACL), thus being able to better withstand the forces that the native ligament experiences. Healing progresses from an early phase, to a remodeling phase and finally a maturation phase, each of which have been extensively studied in animal models, and supported by studies that utilize human graft biopsies. At the time of graft implantation, the tissue is avascular, however it quickly becomes enveloped in synovium and vascularity increases to the point of hypervascularity when compared to a native ACL. At the time of complete maturation, the vascular supply decreases until the normal vascular pattern of the ACL is restored. Immediately after implantation, the graft microstructure progresses from uniformly oriented collagen fibers consistent with the harvested tissue, to a mature state with the graft containing collagen fibers capable of resisting the forces experienced by the native ACL. The biomechanical strength of a graft varies as it undergoes maturation and remodeling, making graft maturity an important aspect in determining when an athlete should return to sport, however the ability to accurately assess the state of graft healing and maturation is currently lacking. This further demonstrates the need for a criterion based program in conjunction with time-based suggestions for timeframes for return after surgery.

The proposed rehabilitation protocol (Appendix 1) is an example of a criterion-based progression that takes time after surgery into account in order to allow for graft healing and maturation. The protocol includes certain time criteria to advance between phases per the surgeon's preference to work in conjunction with criterion-based progression. In the early phases, exercises are specifically selected to meet the early ROM goals, surgeon specific criteria for discharging the brace and crutches, and achieving normal gait. Exercises are then specifically chosen to meet the strength and motor control demands of running, and progressing through functional training to prepare to return to sport.
**Human Graft Biopsy Studies**

Although the graft itself is not vascularized at the time of reconstruction, signs of vascularity are present within the graft as early as three weeks after surgery. The early stage may resolve as early as three months post-operatively, although the transition to the remodeling phase may occur as late as 12 months. The graft then enters the maturation phase between nine and 18 months following surgery. Although it appears the graft undergoes "ligamentization", biopsies have only been obtained from a single sample during the post-operative period.

Graft strength is lowest during the remodeling phase, between two and six weeks, and subsequently improves to final state during the maturation stage. As a result, the graft appears to be most tenuous during the remodeling phase, and measures should be taken to avoid returning athletes to sport until the vascularity of the graft has decreased inferring the end of the remodeling phase of healing.

**Measuring Graft Healing In-vivo**

While the invasive nature of biopsy does not allow serial investigation of graft healing, noninvasive magnetic resonance imaging (MRI) can monitor the progress of healing and maturation of the graft. MRI has been investigated to monitor changes in graft vascularity as a correlate to graft incorporation using signal intensity as a marker of vascularity. The Signal to Noise Quotient (SNQ) standardizes signal intensity of a graft. Serial examinations of individuals that underwent ACL reconstruction with allograft and autograft demonstrated an increase in SNQ on proton density weighted images after implantation followed by a decrease, with signs of graft maturity earlier with autograft (two to six months) compared to allograft reconstructions (nine to 12 months). Ntouia et al specifically examined the maturation of bone-patellar tendon-bone autograft in humans and found vascularity decreased to a state similar to the native ACL between six and 12 months post-operatively.

MRI can be used to show the changes in the biomechanical qualities of a graft. In a study utilizing Achilles tendon autograft in a sheep model, as the graft matured, its SNQ normalized. Fleming et al. examined a goat model with patellar tendon auto-
The risk of re-injury may be greater than when the graft is placed non-anatomically.

**ESTABLISHED RISK FACTORS FOR RE-INJURY AND IMPLICATIONS FOR LATE PHASE REHABILITATION**

In addition to poorer than expected rates of return to pre-injury sport, re-injury or an injury to the contra-lateral knee are common after ACLR. The risk for re-injury to the reconstructed knee requiring revision surgery ranges from 2.6% to 17% five years following ACLR. Contra-lateral knee injury within five years occurs in up to 11.8% (8.2%-16.0%) of individuals. Within the first twelve months after ACLR, the incidence of a second ACL injury is 15 times greater than that of healthy controls experiencing a primary ACL tear.

Time after ACLR is the most frequently cited criteria for allowing individuals to return to sport, which may play a contributory role in ACL injury or rupture. Surgeons may clear a patient to return to sport after a certain timeframe, regardless of functional capacity. Individuals may return to sport between two and 24 months post-operatively, with the average being about seven months. As discussed previously, return to sports within the first year after injury may not be advisable, as re-injury rates are highest during this time. While the six-month time frame may be adequate to ensure that the graft is progressing through the remodeling phase and into the maturation phase, functional performance measures are not related to time from surgery. Therefore, clearance to begin a new activity and progress through the rehabilitation process is dependent upon both functional capacity and time after surgery, and not just a time after surgery requirement. Because of the high rate of re-injury in the first year after ACLR and the time required for the graft to remodel to a somewhat steady state, the program developed at the University of Pittsburgh Medical Center (UMPC) Center for Sports Medicine (Appendix 1) suggests that individuals return to sport around eight to twelve months after ACLR, pending achievement of clinical milestones. The proposed program is based on the best available evidence and is currently being tested in order to determine its effectiveness on both performance improvement and injury risk reduction.

Aberrant movement patterns involving femoral internal rotation and adduction, knee abduction, tibial external rotation and ankle eversion (operationally defined and clinically referred to as “dynamic valgus”) with low knee flexion excursions and large vertical ground reaction forces increase the risk for injury in both the ACLR and healthy populations. However, at least one large study has demonstrated that landing mechanics are not associated with risk for ACL injury. Dynamic valgus observed during landing from jumps and cutting maneuvers is associated with greater ACL injury risk, and may persist after reconstruction. Poor postural stability, weakness of the hip musculature, and dynamic valgus landing mechanics increase the risk of sustaining a second ACL injury. Poor neuromuscular control can lead to a lateral trunk lean increasing the knee abduction moment and strain placed on the ACL, also increasing the risk of injury.

Normalizing mechanics with specific interventions to restore symmetrical and normal movement patterns during rehabilitation following ACLR should be prioritized during the rehabilitation exercise progression. Movement retraining should begin early in rehabilitation during single limb balance tasks, step-down tasks and single leg squats. Movement symmetry and quality with jump-landing and cutting strategies should be the emphasis during the later phases of rehabilitation. During the phase of rehabilitation that allows for plyometrics, education regarding appropriate jumping and landing techniques can improve landing patterns with the use of verbal cues, demonstration of proper and improper landing patterns, increasing landing time, increasing knee flexion angles upon landing, and decreasing vertical ground reaction forces in female high school female athletes. Decreased hip muscle activation has been linked to higher GRF in female athletes who suffered ACL injury and dynamic valgus can be controlled with appropriate hip abductor muscle activation and recruitment. Hip abductor and external rotator strengthening in order to facilitate proper eccentric control during sport specific activities should be included in the rehabilitation program, although activity and sport-specific training to control position of the knee joint is also necessary because a crossover from isolated strengthening
activities to sport specific activities may not occur without task-specific training. Time from injury and neuromuscular control are the only risk factors that have been identified which are modifiable in the return to sport process. Normal mechanics should be stressed during the entire rehabilitation process, as it has been shown that females two years after ACL reconstruction demonstrate limb asymmetries during landing and takeoff phases for the drop vertical jump. Hewett et al. found that excessive knee abduction moments during landing from a drop vertical jump predicted ACL injuries with 73% specificity and 78% sensitivity. For this reason, one of the criteria to advance to the phase that includes cutting in the attached protocol is the demonstration of full motor control and normal mechanics with jumping, i.e. the assessment of mastery.

Individuals must demonstrate mastery of the rehabilitation goals of the current phase before progressing to the next phase. Mastery is typically assessed through observation of the highest level of performance allowed in the progression. Failure to master the tasks of an individual phase is mediated with focused practice and instruction in proper technique. The inclusion of activity mastery as a prerequisite for advancement to the next phase ensures that individuals take time to practice each skill and incorporate good movement patterns during dynamic tasks even if their strength and neuromuscular control would allow them to progress in multiple phases.

Females are four to six times more likely to sustain major knee injuries than men. Female athletes are at high risk for sustaining a primary ACL injury, and the risk of re-injury after ACLR may be four times as high for the ipsilateral knee and six times as high for the contralateral knee in the first year of participation after reconstruction when compared to male athletes. The risk factors and rates of occurrence for a second injury after ACLR in young female athletes are consistent with those established for primary ACL injuries. The effect of gender is likely due to females demonstrating greater dynamic valgus than males, although Smith et al have shown that landing mechanics are not predictive of injury regardless of sex. Female volleyball players demonstrated greater vertical ground reaction forces when performing spike and block landings, although those differences were not seen in a controlled laboratory setting. Again, this demonstrates the need for the assessment of task mastery in each phase and may delay a surgeon clearing a patient for early return to sport. Age plays a role in the risk for re-injury. Individuals younger than 20 have twice the risk of a second injury compared to older individuals. In high school sports, girls have a rate of 7.2 primary or secondary ACL injuries per 100,000 athletic exposures; boys have a 6.2 rate of primary or secondary ACL injuries per 100,000 athletic exposures. The relationship between age and re-injury is further demonstrated when looking at the effect of typical milestones in an American population: school age populations (younger than 18) have a 13% to 17% incidence of secondary injury which decreases when reaching the typical collegiate and post-collegiate ages (18 to 25 years - 7% to 8% secondary injury) and further decreases in those older than 25 years. The greater risk of re-injury in younger individuals is likely due to returning to sports within the first year after ACLR more often than older subjects. This provides a greater exposure to potentially injurious situations in the six to 12 month time period when a majority of re-injuries occur. Other non-modifiable risk factors have been cited, which include joint geometry, familial pre-disposition, and hormonal aspects. The risk for re-injury can be mitigated in spite of some of these non-modifiable risk factors by not allowing athletes to return to sport until healing (as evidenced by normalization of graft vascularity) has occurred and functional performance on objective tests dictates that the individual has achieved symmetrical knee function and demonstrates the elimination of movement patterns that are associated with second injury.

CONSIDERATIONS FOR EARLY REHABILITATION
Before beginning the return to sport phase, basic knee impairments need to be resolved. Full flexion and extension range of motion equal to the contralateral limb needs to be achieved, with referral back to the physician for further assessment suggested if full symmetrical extension is not achieved by one month post-operatively. Referral to the physician may be considered to rule out operative complications, septic arthritis, and localized conditions.
including intra-articular lesions (cyclops lesions), hemarthrosis, or cyst development. Effusion is an outward sign of joint inflammation and should be resolved within the first few months after injury. The stroke test is a reliable test for detecting the presence and quantity of knee joint effusion and has been used clinically to determine tolerance to functional activities in response to increases in exercise intensity, (i.e. if joint effusion increases after the introduction of an activity, the knee is not ready to continue that activity). Joint effusion may reflexively inhibit the quadriceps, limiting force production, delaying recovery, however the mere absence of a joint effusion is not sufficient to assume that full quadriceps activation is present. Numerous criterion based protocols and reviews are available to guide appropriate early post-operative rehabilitation. The recommendations throughout the rest of this manuscript assume full active and passive motion has been achieved; and that the individual demonstrates good quadriceps activation and can perform a straight leg without a lag.

**THIGH MUSCLE STRENGTH SYMMETRY**

Periods of disuse after injury and ACLR can result in quadriceps muscle strength asymmetry between the injured and uninjured limbs. Individuals with strength deficits of the involved limb perform worse on patient-reported outcome measures and performance-based functional tests. These weaker individuals jog similarly to injured subjects with truncated knee motion and have a greater incidence of anterior knee pain and early onset development of osteoarthritis. Quadriceps asymmetry of 20% or more is frequently seen in individuals six months after ACLR and the incidence may be as high as 24% of individuals one year after ACLR. The pre-return to sport time frame needs to incorporate aggressive quadriceps strengthening, including both non-weight bearing (NWB) and weight bearing (WB) exercises in order to assist the athlete in regaining full strength. Non-weight bearing leg extension exercises are frequently avoided because they can place undue strain on the graft, however, quadriceps contractions in the range from 90° to 50° of knee flexion do not exert an unsafe anterior translation force on the tibia, thus do not place excess strain on the graft and are appropriate and safe to use after ACL reconstruction. Non-weight bearing exercises between 90 degrees and 60 degrees of knee flexion should be implemented immediately after ACLR to provide isolated resistance to the quadriceps. At four months post-ACLR as the graft remodeling phase peaks, the range of motion for NWB exercise can be progressed about five degrees per week to slowly increase the load experienced by the ACL. The amount of resistance selected should be based upon the presence of any patellofemoral pain. In weight bearing, quadriceps strengthening exercises should be performed from 0 degrees to 45 degrees, since the hamstrings are active in more extended ranges of the knee. At approximately three months post-op, the range of motion for closed chain exercises can be progressed gradually as the graft is expected to be transitioning to the maturation phase.

Neuromuscular electrical stimulation (NMES) can facilitate re-education of the quadriceps, particularly when quadriceps activation is inhibited due to pain, effusion, or muscle atrophy, to help restore quadriceps strength. The use of high intensity NMES improves patient reported outcome scores, volitional activation of the quadriceps, and facilitates a greater proportion of individuals to meet criteria for progression to agility exercises. Neuromuscular electrical stimulation can be completed with the knee joint in full extension to promote quadriceps activation during terminal knee extension and can be used immediately after surgery. A transition to application of neuromuscular electrical stimulation with the knee positioned between 60 and 90° of flexion in the isometric mode on an isokinetic dynamometer can help to ensure a therapeutic dose of electrical stimulation when the intensity is set to ≥50% maximum voluntary isometric torque. Contraction of the hamstrings can assist in resisting anterior tibial translation and reducing strain on the graft; however, hamstring strength is not associated with functional outcomes. Individuals undergoing ACLR with hamstring autografts may present with greater hamstring strength deficits when compared to those who have had other grafts. These strength deficits may be greater when both the semitendinosus and gracilis are harvested, as compared to harvest of the semitendinosus only, especially at
greater knee flexion angles. For all patients who have received a hamstring autograft, isolated hamstring strengthening should be included in the return to sport progression, including NWB hamstring curls, unilateral bridges, exercise ball hamstring curls, and Nordic hamstring exercises to normalize any hamstring strength deficits that may be present.

Quadriceps strength symmetry of 80% is recommended before the initiation of running, and greater than 90% before returning to sports. The European Board of Sports Rehabilitation recommends the more stringent criteria of 100% strength symmetry as measured by a battery of tests for returning to competitive, pivoting, or contact sports. Hamstring to quadriceps (H:Q) strength ratios may indicate how effectively the hamstring muscles can counteract anterior tibial translation. A H:Q ratio of at least 85% has been recommended before clearing athletes to return to sport; however, improvements in the H:Q ratio should not be made at the expense of quadriceps strength.

**CONCLUSION**

Return to pre-injury level of sports participation after ACL reconstruction is often suboptimal and the risk for graft injury or contralateral injury requiring additional surgery is significant. Younger athletes are more likely to return to sport within the first year after reconstruction but there is a greater risk of re-injury and risk of contralateral injury. Resolving impairments while eliminating movement patterns associated with injury and allowing sufficient time for graft healing to occur likely gives the athlete the best chance to return to sport without further incident. At this time, using MRI to investigate graft healing is promising; however, it has not been validated to ensure graft maturity and biomechanical strength. Additional research is needed to identify objective imaging and functional testing criteria to improve clinical decision making for the return to sport phase after ACL reconstruction.

**CLINICAL RECOMMENDATIONS WITH SORT GRADES**

**Grade A.** Return to sport rates vary considerably based on patient age, sex, and type of sport. Patient education should reflect this variability.

**Grade B.** Because re-injury or contralateral injury risk is significant and most likely to occur within the first year after surgery, patients should be encouraged to delay return to sport pending graft healing timeframes and full resolution of impairments, and functional excellence.

**Grade B.** Quadriceps strength should be explicitly measured and symmetry restored before beginning the return to sport phase in order to limit aberrant movements with sport specific activity.

**REFERENCES**


APPENDIX 1: UPMC CENTER FOR SPORTS MEDICINE POST-OP ACL PROTOCOL, CURRENTLY BEING RESEARCHED.

**ACL Reconstruction Functional Rehabilitation Protocol**

Formal physical therapy and sport specific training will last 8-12 months. All patients will be issued a neuromuscular electrical stimulation unit (NMES) for home use with guidelines. A continuous passive motion (CPM) device will be issued at the physician’s discretion.

**Activities of Daily Living Guidelines Following Surgery**

Patients may begin the following activities at the timeframes indicated (unless otherwise specified by the physician):

- No bathing or submerging the wound in water until the sutures have been removed, the scabs have fallen off, and the skin is completely closed
- Showering is allowed after the surgical dressing is removed; a waterproof dressing is not needed as the incision can get wet. A shower seat is advised to avoid falls
- The brace will be locked in extension for gait and sleep for the first week
- Use of crutches and brace for ambulation for 4-6 weeks. Must be cleared by physician and/or physical therapist to begin walking without assistive devices

- Weight-bearing as tolerated immediately after surgery unless otherwise instructed
- For R knee surgery, no driving for 4-6 weeks. As long as they are in the brace, patients are medically liable if in an accident. For L knee surgery, patients may drive after one week as long as they have an automatic and have stopped taking narcotics.
  - Must pass driving test for R knee: While sitting, complete eight fast foot taps over shoe then stand up

**Brace and Crutch Use Guidelines**

Patients will be WBAT after surgery. The post-op brace is locked in extension initially for the first week with the exception that it may be unlocked for post-op exercises and CPM use. It is unlocked for walking once the patient reaches full knee hyperextension, usually 1 week post-op.

**BRACE IS DISCONTINUED WHEN:**

- The patient is at least 4-6 weeks post-op
- The patient has full and equal passive and active knee hyperextension and >100° flexion
  - Active knee extension is measured via straight leg raise
- The patient demonstrates normal pain-free walking without an increase in swelling

**CRUTCHES ARE DISCONTINUED WHEN:**

- The patient will initially be WBAT with bilateral crutches for 4 weeks; they will then transition to one crutch before walking without the crutches over the next 2 weeks
The patient has full and equal passive and active knee hyperextension and >100° flexion
The patient is able to walk and maintain the knee in full extension without use of assistive device (i.e. does not walk with “bent knee” gait pattern)
The patient has no increased knee pain or swelling with independent weightbearing

Special weightbearing guidelines for concomitant procedures
- The brace will be worn at least 6 weeks for combined ACL/ MCL procedures, concomitant meniscal repairs, and microfracture procedures
- **MENISCUS REPAIR**: Patients that also undergo a meniscus repair procedure will be NWB for 4 weeks, 50% WB for 2 weeks, then WBAT after 6 weeks
- **MICROFRACTURE or ARTICULAR CARTILAGE PROCEDURE**: Patients that also undergo a microfracture or articular cartilage procedure will be NWB for 4 weeks, 50% WB for 2 weeks, then WBAT after 6 weeks

**Estimated Return to Sport Milestones (based on graft healing time and passing functional testing):**

<table>
<thead>
<tr>
<th>Bone-Patellar Tendon-Bone Autograft</th>
<th>Jogging</th>
<th>Low-level Agility</th>
<th>Jumping</th>
<th>Cutting</th>
<th>Return to Sport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone-Patellar Tendon-Bone Autograft</td>
<td>4-5 months</td>
<td>5-6 months</td>
<td>6-7 months</td>
<td>7-8 months</td>
<td>9+ months</td>
</tr>
<tr>
<td>Hamstring/Quad Tendon Autograft</td>
<td>4-5 months</td>
<td>5-6 months</td>
<td>6-7 months</td>
<td>7-8 months</td>
<td>9+ months</td>
</tr>
<tr>
<td>Bone-Patellar Tendon-Bone Allograft</td>
<td>5-6 months</td>
<td>6-7 months</td>
<td>7-8 months</td>
<td>8-9 months</td>
<td>10+ months</td>
</tr>
<tr>
<td>Soft Tissue Allograft</td>
<td>5-6 months</td>
<td>6-7 months</td>
<td>7-8 months</td>
<td>8-9 months</td>
<td>10-12+ months</td>
</tr>
</tbody>
</table>

These times are estimated based on graft healing and are dependent upon the patient passing functional testing in physical therapy that assesses strength and neuromuscular control. These times may be longer if the patient also had a concomitant procedure such as a meniscal repair, microfracture/articular cartilage procedure or other ligament injury or procedure. They physician may also order an MRI to assess graft healing to assist in making return to sports activity decisions.

**Phase 1: Initial Post-Op Care**
Goals for Phase 1 include restoration of ROM and mobility, management of pain and edema, and initiation of strengthening with emphasis on the quadriceps. The post-operative brace may be removed for treatment. Closed kinetic chain (CKC) exercises should be performed in the protected range of 0-45° of flexion and open kinetic chain (OKC) knee extension exercises should stay in the protected range of 90-60° of flexion. Exercises should include but are not limited to:

**Weeks 1-4:**
- 4-way patellar mobilization
- High intensity neuromuscular electrical stimulation
- Exercises to regain hyperextension – hamstring and gastrocnemius stretching, prone hang, manual overpressure, seated heel props with bag hang and/or with cuff weights
- Exercises to regain full flexion – heelslides, posterior tibial mobilizations
  - NOTE: Flexion is limited to 90° for 4 weeks with concomitant meniscus repairs
- Early strengthening – quad sets in full knee hyperextension, 4-way straight leg raises, terminal knee extension (CKC), mini-squats, isometric quadriceps setting at 90° and 60° of knee flexion
- Balance and proprioception exercises – progressing from weight shifting during bilateral stance progressing to unilateral stance exercises on stable and unstable surfaces, with eyes open and eyes closed
- Gait training – weight-shifts (side to side and forward/ backward)
- Progress strengthening to include – leg press (single leg), OKC knee extension from 90-60° with ankle cuff weights, step-ups, step-downs, bridges, hamstring curls, wall slides
  - NOTE: No OKC hamstring curls with concomitant meniscal repair or hamstring autograft for first 6 weeks

**Goals at 2 weeks post-op include:**
- Passive and active hyperextension (as measured when doing a straight leg raise) should be equal to the uninvolved side and flexion >100°
- Reduced pain and swelling (rated 2+ or less via Stroke Test)
- If SLR doesn’t reach neutral extension (0°) by 2 weeks post-op, increase frequency of PT and notify the physician

**Goals at 4 weeks post-op include:**
- Full flexion (unless ROM restriction from concomitant meniscus repair)
- No active inflammation (i.e. no increased pain, swelling or warmth) as a result of exercise. Swelling should be rated 1+ or less via Stroke Test
- Preparation for full weightbearing and independent gait

The patient’s visit frequency will be set by the PT for 1-3 times per week. If the patient is not meeting the range of motion milestones or if they are having difficulty with regaining quadriceps control/have a knee extensor lag, the MD should be notified and visit frequency should increase.

**Weeks 4-16:**
- Stretching exercises and manual therapy if flexion or extension is still limited
- Cardio – bike, elliptical
- Gait training on treadmill progressing to fast treadmill walking
- Aquatic therapy (if available) – 4-way straight leg raises, squats, bicycle kicking, fast walking progressing to a jog
- Progress strengthening to include – OKC knee extension (90-60° for the first 10 weeks, 90-45° for weeks 10-16), single leg squats, lunges, mini-band walking, deadlifts, step and holds (Individual steps from the uninjured limb onto the injured limb, at least the distance of the individual’s normal stride length. The individual is cued to imagine they are stepping over a puddle of water and to land with a heel-toe gait pattern to simulate walking and progressing the distance to prepare for running without excessive stiffening or excessive knee flexion)
- Perturbation training
PT should focus on aggressive strengthening, particularly of the quadriceps. Visit frequency may be reduced if the patient has regular access to weight training equipment at a gym.

**Weeks 16-20:**
- CKC exercises should be progressed to ~60-75° of knee flexion provided that this does not cause any patellofemoral pain.
- OKC exercises should be progressed to full range 90°-0° provided that this does not cause any patellofemoral pain.
- Prepare to pass screening exam to begin running

**Goal at 4-6 months post-op (depending on graft type):**
**PASS SCREENING TEST TO BEGIN RUNNING**
- No abnormal gait patterns while walking as fast as they can on the treadmill for 15 minutes
- 30 step and holds without loss of balance or excessive motion outside of the sagittal plane
- 10 consecutive single leg squats to 45° of knee flexion without loss of balance, abnormal trunk movement, Trendelenburg sign, femoral IR or the knee deviating medially causing the tibial tuberosity to cross an imaginary vertical line over the medial border of the foot
- ≥ 80% 1-repetition maximum (1-RM) on the leg press (90-0°)
- ≥ 80% 1-repetition maximum (1-RM) on the knee extension machine (90-45°)
- ≥ 90% composite score on Y-balance test. Composite score = (anterior reach + posteromedial reach + posterolateral reach)/(3 x limb length)

**Phase 2: Running**
Begin jogging on a treadmill or a track when the patient passes the screening exam AND is cleared by the physician. Running should begin at slow, comfortable speeds for short durations and distances. The patient may progress in speed, time and distance as long as there is no development or increase in pain, swelling, warmth, or gait deviations. See Running Progression Guidelines handout.

The patient should be seen by the physical therapist once every 2-3 weeks while running tolerance and endurance progresses. Aggressive strengthening should continue in preparation to pass the screening test to begin agility drills.

Patients who undergo a Quadriceps tendon autograft with bone plug will need an x-ray at their 6 month post-op visit in order to be cleared for Biodex testing to ensure healing of the harvest site.

**Goals at 5-7 months post-op: PASS SCREENING TEST TO BEGIN LOW-LEVEL AGILITY DRILLS**
- ≥ 85% 1-RM on the leg press (90-0°)
- ≥ 85% 1-RM on the knee extension machine (90-0°) or Biodex testing if available
- 10 consecutive single leg squats >45° of knee flexion without loss of balance, abnormal trunk movement, Trendelenburg sign, femoral IR or the knee deviating medially causing the tibial tuberosity to cross an imaginary vertical line over the medial border of the foot while holding ≥ 75% extra weight compared to the other side (dumbbells, weight vest, etc.) Body weight is not part of the equation
- 100% composite score on Y-balance test. Composite score = (anterior reach + posteromedial reach + posterolateral reach)/(3 x limb length)
- Be able to run 2 miles continuously without pain, swelling, warmth, or gait deviations

**Phase 3: Agility Training**
When the patient passes the screening exam AND is cleared by the physician, they may begin agility drills that include lateral shuffling, forward/backward shuttle runs, carioca, and ladder drills.

Physical therapy should focus on elimination of compensation patterns, particularly when the patient decelerates. Aggressive strengthening should continue in preparation to pass the screening test to begin jumping.

If the patient is not planning to return to sports participation, they may be discharged from PT once they are able to do agility training at sub-max speeds without new inflammation.

**Goals at 6-8 months post-op: PASS SCREENING TEST TO BEGIN JUMPING**
- ≥ 90% 1-RM on the leg press (90-0°)
- ≥ 90% 1-RM on the knee extension machine (90-0°) or Biodex testing if available
- 10 consecutive single leg squats to 60° of knee flexion without loss of balance, abnormal trunk movement, Trendelenburg sign, femoral IR or the knee deviating medially causing the tibial tuberosity to cross an imaginary vertical line over the medial border of the foot while holding ≥ 85% extra weight compared to the other side (dumbbells, weight vest, etc.). Body weight is not part of the equation

**Phase 4: Jumping (Two Feet)**
When the patient passes the screening exam AND is cleared by the physician, begin jumping. Jumping is with two feet, both taking off and landing.

Jumps should start with single vertical jumps and the physical therapist should watch for medial collapse of the knees both when loading into the jump and landing from the jump. When the patient demonstrates consistent equal weightbearing when landing, progress with forward, side to side, rotating, and box jumps. As the patient demonstrates consistent good form, progress from single jumps to consecutive jumps.

Physical therapy should focus on teaching the patient soft, athletic landings and avoidance of compensation strategies. Aggressive strengthening should continue in preparation to pass the screening test to begin hopping and cutting.

**Goals at 7-9 months post-op: PASS SCREENING TEST TO BEGIN CUTTING AND HOPPING**
- 10 consecutive single leg squats to 60° without loss of balance, abnormal trunk movement, Trendelenburg sign, femoral IR or the knee deviating medially causing the tibial tuberosity to cross an imaginary vertical line over the medial border of the foot while holding ≥ 90% extra weight compared to the other side (dumbbells, weight vest, etc.). Body weight is not part of the equation
• No display of medial collapse of the knees when loading into or landing from jumps, and equal weight distribution when initiating and landing the jumps

**Phase 5: Hopping (Single Leg) and Cutting**

When the patient passes the screening exam AND is cleared by the physician, they may begin hopping and cutting. Hopping is with 1 foot, both taking off and landing. Hopping should follow the same progression as jumping.

Patients should first practice running in an ‘S’ pattern, then progress to 45° cuts, and then to sharper angles. Pivoting and cut and spinning should begin when the patient is competent with cutting at sharp angles. Patients should be able to tolerate cutting, pivoting and cut and spinning at full speed before practicing unanticipated cutting. The patient should not progress their speed if they demonstrate any excessive knee medial deviation or express a lack of confidence when cutting.

Sprinting should begin with transitions from running directly into sprinting short distances. Distance should be progressed to sprinting a 40 yard dash, then a 100 yard dash, and finally sprints to fatigue.

Physical therapy should focus on improving the form and speed of hopping and cutting. Aggressive strengthening should continue in preparation to return to sports participation.

**Goals at 9-12 months: PREPARE TO TAKE RETURN TO SPORTS TEST**

- Display a normal running pattern that does not increase pain, swelling, or warmth
- Practice and display no hesitation or compensation strategies during agility drills (particularly when decelerating) when performed at 100% effort
- Practice and display normal loading (no medial knee collapse) and soft, athletic landings from all jumps and hops
- Practice and display no hesitation or compensation strategies during cutting drills (particularly when decelerating) when performed at perceived 100% effort

**Returning to Sports Participation**

The patient should be able to perform all agility, plyometric, and cutting exercises at full speed without compensation patterns or complaints of pain, swelling, or warmth. Exercises should include anticipated and unanticipated cutting and jumping.

Physical therapy should be geared on sport specific training as per the patient's sport and position.

The patient may return to sports participation when they pass the ACL Return to Sports Test AND receive clearance by the physician.

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**Post-Op ACL Reconstruction Return to Sport Test**

Name:________________________ Date:____________

1. Single broad jump, landing on one foot - Involved/Uninvolved Distance = _______/_______ = _______
2. Triple broad jump, landing last jump on one foot – Involved/Uninvolved Distance = _______/_______ = ______
3. Single leg forward hop - Involved/Uninvolved Distance = _______/_______ = ______
4. Single leg triple hop - Involved/Uninvolved Distance = _______/_______ = ______
5. Single leg triple crossover hop - Involved/Uninvolved Distance = _______/_______ = ______
6. Timed 6-meter single leg hop - Uninvolved/Involved Time = _______/_______ = ______
7. Single leg lateral hop - Involved/Uninvolved Distance = _______/_______ = ______
8. Single leg medial hop - Involved/Uninvolved Distance = _______/_______ = ______
9. Single leg medial rotating hop - Involved/Uninvolved Distance = _______/_______ = ______
10. Single leg lateral rotating hop - Involved/Uninvolved Distance = _______/_______ = ______
11. Single leg vertical hop - Involved/Uninvolved Height = _______/_______ = ______

12. 10 yard Lower Extremity Functional Test
   - Sprint/back-peddle, Shuffle, Carioca, Sprint
   - Must perform at perceived full speed and not display hesitation or compensation strategies when decelerating
   - Recommended goal for males: 18-22 seconds; females: 20-24 seconds

13. 10 yard Pro-agility Run
   - Both directions
   - Must perform at perceived full speed and not display hesitation or compensation strategies when decelerating
   - Recommended goal for males: 4.5-6.0 seconds; females: 5.2-6.5 seconds

**Criteria to Return to Practice:**

1. MD clearance
2. Pass Return to Sport Test with ≥90% results for each test.

**Criteria to Return to Competition:**

1. MD clearance
2. Tolerate full practice sessions with opposition and contact (if applicable) performed at 100% effort without any increased pain, increased effusion, warmth, or episodes of giving way.
ABSTRACT

The incidence of rotator cuff tears increases with age, with full-thickness rotator cuff tears present in approximately 25% of individuals in their sixties, and more than 50% of those in their eighties. While surgery is considered an effective treatment, recurrent tears at the insertion site are common, especially with degenerative tears, which are frequent in the older population. More recently, there has been increasing interest in exercise rehabilitation and physical therapy as a means to manage partial and full thickness tears of the rotator cuff by addressing weakness and functional deficits. Recent studies have suggested that patients opting for physical therapy have demonstrated high satisfaction, an improvement in function, and success in avoiding surgery. When considering the increasing rate of shoulder surgery and the associated economic and social burden rotator cuff surgery places on both the patient and the health care system, non-surgical management such as physical therapy and exercise may, in selected cases, be a treatment alternative to surgical repair. The purpose of this clinical commentary is to provide an overview of rotator cuff pathology and pathogenesis, and to present an evidence-based case for the role of conservative rehabilitation in the management of rotator cuff injuries.

Level of Evidence: Level 5

Keywords: Conservative management; exercise rehabilitation; physical therapy; rotator cuff tear
INTRODUCTION

Full thickness tears of the rotator cuff are among the most frequently encountered causes of pain and dysfunction in the shoulder complex, becoming more prevalent due to an ageing population and the increased functional demands in older people. Chronic rotator cuff pathology has attracted attention due to the considerable disability, poor quality of life and expensive utilization of health care resources. In the United States alone, tears of the rotator cuff affect at least 10% of those over the age of 60, equating to over 5.7 million people and resulting in an estimated 75,000–250,000 rotator cuff surgeries performed per year. In Australia, this figure is approximately 14,000 annually, with direct medical expenses for rotator cuff repair estimated at $250 million per year. Therefore, it is important to investigate possible solutions to reduce the increasing economic and social burden that rotator cuff repair places on patients and health care systems around the world.

To date, evidence regarding the management of rotator cuff tears has produced conflicting results. Some authors consider that surgery for rotator cuff tears offers better outcomes than non-operative treatments; while others have argued that non-operative interventions produce equivalent outcomes to surgery. Those advocating operative treatment suggest that repair of the rotator cuff tendon (especially early in the disease process) may alter the pathogenesis of rotator cuff disease and protect and/or prevent tear progression, tissue degeneration, biceps involvement and glenohumeral joint (GHJ) degeneration. Those in favor of non-operative interventions argue that for selected patients, addressing the clinical and functional deficits via conservative management may be effective in reducing pain and symptoms, providing a worthy alternative to surgery. The purpose of this clinical commentary is to provide an overview of rotator cuff pathology and pathogenesis, and to present an evidence-based case for the role of conservative rehabilitation in the management of rotator cuff injuries.

EPIDEMIOLOGY

Shoulder pain is the third most common musculoskeletal complaint reported to general practitioners in primary care settings. In developed countries, approximately 1% of the adult population is expected to visit a general practitioner annually for shoulder pain. While it is estimated that 65–70% of all shoulder pain involves the rotator cuff tendon, it has been estimated that 5 to 40% of people without shoulder pain have full-thickness tears of the rotator cuff. Rotator cuff tears can be classified by the mechanism of injury: acute, chronic or a combination of both (acute on chronic). An acute rotator cuff tear has been defined as a tear involving an injury or trauma, typically appearing in patients with no previous history of shoulder symptoms, and presenting with pseudoparalysis of the shoulder. Chronic rotator cuff tears often occur due to progressive degeneration of the tendon, developing over time and typically due to multiple factors such as over-use, a lack of blood supply and other physiological factors. Additionally, chronic cuff tears that may be asymptomatic may be aggravated by trauma, which is known as acute on chronic. Irrespective of the mechanism of the injury, rotator cuff tears can be classified into two broad types: partial-thickness or full-thickness. Partial-thickness tears are generally more frequent than full-thickness tears, with a prevalence of 13% versus 7.

Rotator cuff tears are generally considered a normal, age-related degenerative disorder, which can be symptomatic, or asymptomatic. Little information is available as to why some rotator cuff tears are painful while others are completely asymptomatic. Symptomatic tears are generally seen in the dominant shoulder (only 28% of patients in the non-dominant shoulder only), with bilateral tears present in 36% of patients. In a cadaveric study, full-thickness tearing of the rotator cuff was observed in 6% of cadaver specimens under 60 years of age, and 30% in those older than 60. Other authors have used magnetic resonance imaging (MRI) and ultrasound in an attempt to determine the presence of rotator cuff tears in asymptomatic shoulders. Sher et al observed tears in 34% of asymptomatic individuals, with 15% of those classified as full-thickness tears and 20% as partial thickness. No individuals under 40 years of age displayed full-thickness tears, and only 4% had partial-thickness tears. In patients between 40-60 years of age, full-thickness and partial-thickness tears were observed in 4% and 24% of individuals, respectively; and in individuals older than 60 years of age, this increased to 28% and 26%, respectively.
Tempelhof et al\textsuperscript{16} reported an overall prevalence of full-thickness rotator cuff tears in asymptomatic individuals to be 23\%, with 51\% of individuals over 80 years of age displaying tears. A limitation of this study was that the authors only evaluated asymptomatic shoulders. Interestingly, rotator cuff disease appears to be a bilateral condition. Yamaguchi et al\textsuperscript{13} reported that if patients had a symptomatic rotator cuff tear, there was a 35\% chance of a cuff tear on the opposite side which increased to 50\% if the patient was 66 years of age or older. Despite not being painful, asymptomatic rotator cuff tears are at risk of becoming symptomatic over time. The average size of a symptomatic tear has been shown to be 30\% greater than that of an asymptomatic tear.\textsuperscript{13} Yamaguchi et al\textsuperscript{8} followed asymptomatic rotator cuff tears over a five-year period to assess the risk for development of symptoms and tear progression using ultrasound and clinical assessment. 51\% of these tears progressed to symptomatic tears at a mean of 2.8 years after initial examination. Furthermore, 50\% of those who became symptomatic demonstrated tear progression compared with 22\% of those who remained asymptomatic.

**RELEVANT ANATOMY AND BIOMECHANICS**

The rotator cuff contributes to both stability and movement of the glenohumeral joint (GHJ) and is integral to appropriate functioning of the upper limb.\textsuperscript{17} It is a myotendinous complex formed by four muscle-tendon units: the supraspinatus superiorly, the subscapularis anteriorly and the teres minor and infraspinatus posteriorly.\textsuperscript{18} The tendons of the rotator cuff are composed primarily of type 1 collagen fibers tightly packed in a parallel configuration with small numbers of long, thin tenocyte cells in between the rows of collagen. The collagen fibers and cells are embedded in a matrix of proteoglycans, glycosaminoglycans, and water.\textsuperscript{19} A commonly held view is that the four rotator cuff tendons are separate entities.\textsuperscript{20} However, Clark and Harryman\textsuperscript{18} showed that these four tendons fuse together approximately half an inch from the point of the insertion of the tendons into the humerus. Prior to their fusion, the triangular space between the supraspinatus and subscapularis, known as the rotator interval, houses the coracohumeral ligament, middle glenohumeral ligament and superior glenohumeral ligament, and the long head of the biceps tendon, which provides stability in the GHJ.\textsuperscript{21} The infraspinatus and teres minor join together at their musculotendinous junctions, and then fuse with the supraspinatus approximately 15mm proximal to the insertion site,\textsuperscript{11} and then fuse together with the subscapularis over the bicipital groove and into the greater tuberosity of the humerus.\textsuperscript{11} When examined microanatomically, both the supraspinatus and infraspinatus tendons are composed of five layers.\textsuperscript{18} The most superficial layer is composed of the fibers of coracohumeral ligament; layers two and three are thick tendinous structures, layer four is composed of loose connective tissue and layer five is the joint capsule of the shoulder.\textsuperscript{18} Between the fourth and fifth layers, a strip of fibrous tissue extends from the coracohumeral ligament through the supraspinatus tendon on the articular side to the inferior border of the infraspinatus tendon, referred to as the rotator cable.\textsuperscript{22} Together with an area of thinner cuff tissue localized lateral to the cable, a biomechanical model has been described, termed the ‘cable-crescent’ complex.\textsuperscript{23} This complex was described in a cadaveric study by Burkhart et al\textsuperscript{23} who likened it to a suspension bridge, influencing GHJ mechanics by transferring force from medial tendon fibres through the loaded cable to the humerus, ultimately stress-shielding the crescent tissues.\textsuperscript{24}

Classification systems for tears of the rotator cuff tendon have been proposed based upon specific characteristics such as size of the lesion, number of tendons involved, and the reparability of the tear.\textsuperscript{25-30} While the definition of a “massive” tear has not yet been clearly standardized, tears greater than 5 cm, or complete tears involving at least two tendons are considered “massive”. In addition to these broader-based classifications, specific classification systems focusing on individual tendons have also been proposed. Patte\textsuperscript{27} developed a classification for lesions of the supraspinatus, infraspinatus and teres minor, Lafosse et al\textsuperscript{26} for tears of the subscapularis, and Ellman et al\textsuperscript{28} for partial rotator cuff tears. Most rotator cuff tears occur in the tendinous part of the cuff, where the tendons from the corresponding muscles are not individualized.\textsuperscript{31} Location of tears are given in terms of the tendons involved, by differentiating between superior tears (affecting the supraspinatus tendon only), superoposterior tears (affecting
the supraspinatus and infraspinatus tendons) and superoanterior tears (affecting the supraspinatus, the rotator interval, the subscapularis and sometimes the long head of the biceps).27

Superior tears involving solely supraspinatus tendon have traditionally been considered the most common, and indeed this is the location where many tears initiate and propagate from due to the location of the supraspinatus under the coracohumeral ligament.32 However, Kim et al33 analyzed tears in 360 shoulders, and reported that 83% of full-thickness tears and 72% of partial thickness tears were commonly located more posterior than originally thought, approximately 15mm posterior to the biceps tendon. This suggests that most degenerative cuff tears initiate from a region near the junction of the supraspinatus and infraspinatus tendons. Superior rotator cuff tears not involving the cable may be described as biomechanically "intact" and functional. Because the the rotator cable remains intact, it is possible and may explain commonly reported anecdotes whereby an individual with a moderate or large chronic cuff tear is able to preserve normal shoulder function without symptoms. In superoposterior tears larger than medium-sized, the involvement of the subscapularis tendon is three times more likely. These tears interrupt the rotator cable, and alter the normal kinematics of the glenohumeral joint. Complete tears that exceed 50% of the subscapularis tendon increase the risk of pseudoparalysis in patients with massive rotator cuff tears.34,35

The ‘intrinsic’ rotator cuff muscles act in synergy to maintain GHJ stability by compressing and centralizing the humeral head into the glenoid fossa.36 Their combined GHJ stabilizing role is imperative for shoulder complex stability and function as the larger ‘extrinsic’ muscles, such as the latissimus dorsi, pectoralis major and deltoid, produce the forces necessary for gross arm and shoulder movements. Electromyography (EMG) studies have demonstrated that rotator cuff muscular activity precedes deltoid and pectoralis major EMG activity during volitional movement,37 suggesting that the rotator cuff muscles dynamically compress and stiffen the GHJ in preparation for larger destabilizing global muscular contractions. The supraspinatus muscle is the primary superior compressor of the humeral head and resists the superior force exerted by the deltoid muscle.36 The stabilizing mechanism at the GHJ is largely dependent on the entire rotator cuff, specifically, the transverse force coupling provided by the anterior (subscapularis) and posterior (infraspinatus / teres minor) tendons with their insertion into the proximal humerus.36 Pre-activation of the rotator cuff muscles has also been demonstrated in a direction specific manner with anterior and posterior rotator cuff muscles working individually to oppose rotational force and maintain a neutral position,38 effectively “steering” the humeral head within the glenoid. Any disruption to these ‘force couples’, especially with respect to rotator cuff tears, is likely to contribute to shoulder dysfunction. Tears can cause disruption of normal shoulder kinematics by altering the force balance between the subscapularis and infraspinatus.39 Clinically, patients with rotator cuff tears can have preserved function if the integrity of the transverse force couple balance is maintained.11 However, if the tear progresses to involve the posterior cuff musculature, this balance of forces is often disrupted, GHJ stability is lost, and a stable fulcrum for concentric rotation of the humeral head in the glenoid no longer exists.39

**CLINICAL PRESENTATION**

The clinical presentation of an individual with a diagnosed rotator cuff tear varies, dictated by a number of variables including the location and size of the tear. Some patients present without significant pain, symptoms and/or dysfunction, while others report severe pain and demonstrate loss of strength and function. However, the reason why some tears are and may remain asymptomatic is not fully understood. Patients with a symptomatic rotator cuff tear typically present with shoulder pain and cuff weakness. Constant pain and a painful arc (pain during abduction between 70-120 degrees) are strong predictors of tears of the supraspinatus tendon. These patients also typically present with a loss of active shoulder abduction and elevation, weakness and reproduction of pain during resisted abduction or external rotation,40 and positive impingement signs.41 In addition, superoposterior tears show a loss of active range of motion and weakness in external rotation with a positive lag sign,42 while tears of the subscapularis may result in reduced active...
range of motion, weakness in internal rotation and an abnormal “lift off” sign. A recent clinical study demonstrated that tears exceeding more than half of the subscapularis tendon increased the risk of pseudoparalysis in patients with massive rotator cuff tears. Dysfunction of scapulohumeral rhythm and a compensatory shoulder shrug may be observed during active abduction and elevation. Finally, patients with long-standing rotator cuff tears may present with obvious atrophy, with muscular wasting in the supraspinatus also commonly associated with a concomitant infraspinatus tear.

RELEVANT PATHOPHYSIOLOGY OF ROTATOR CUFF TEARS

The pathogenesis of rotator cuff tears is not fully understood, but is considered to be a combination of ‘extrinsic’ factors such as impingement from structures surrounding the cuff, and ‘intrinsic’ factors such as tissue-based degenerative tendon changes that may occur with normal aging and mechanical overuse from repetitive activities. A ‘degeneration-microtrauma’ theory has been developed, proposing that repetitive stresses lead to small injuries within the tendon that are given an insufficient time to heal before further trauma. The combination of reduced tensile strength and either a single traumatic insult, or progressive microtrauma, can then lead to cuff tearing. Furthermore, after the deep fibers tear, fiber retraction results in an increased load on the remaining fibers that subsequently increases the likelihood of progressive tendon rupture. As a result of repetitive microtrauma in a degenerative rotator cuff tendon, inflammatory mediators alter the local environment and oxidative stress induces tenocyte apoptosis, causing further rotator cuff tendon degeneration. Yuan and Murrell first described the role of apoptosis in rotator cuff tendon disorders, demonstrating an increase of apoptotic cells in the degenerative supraspinatus tendon (34%) compared with the normal subscapularis tendon (13%). The increased number of apoptotic cells in degenerative tendon could affect the number of functional tendon fibroblasts which may contribute to an impaired rate of collagen synthesis and repair resulting in a weaker tendon thereby promoting tendon degeneration and eventually increasing the risk of rupture. Extrinsic factors involve pathological contributions external to the tendon tissue that may occur as a consequence of anatomical variables such as the shape of the acromion, which may then cause tendon compression during shoulder motion. The chronic impingement syndrome theory described by Neer is a well-known theory, which proposed that the impingement of the rotator cuff tendon against the inferior part of the acromion and coracoacromial ligament was the primary factor in causing tissue damage and tendon tears. Bigliani et al found a higher prevalence of rotator cuff tears in patients with a hooked (type III) acromion morphology compared to individuals with a curved (type II) or a flat (type I) acromion. Wang et al showed that the success of conservative management decreased with changes among these three types of acromion shape: type I responded in 89% of cases, type II in 73% and type III in 58.3%.

ROTATOR CUFF SURGERY

Common surgical interventions include a rotator cuff tendon repair, involving reattachment of the torn cuff tendon to the humeral insertion site, and/or decompression to increase the size of the subacromial space. In support of the extrinsic factor of pathology and the mechanical theory, Björnsson et al reported that arthroscopic subacromial decompression reduced the prevalence of rotator cuff tears in patients with impingement, with 82% of patients exhibiting intact tendons 15 years after surgery. Subacromial decompression is performed when there is significant impingement of the rotator cuff tendon between the acromion and humerus, and may be performed as either an arthroscopic or open surgery. Tendon repair is performed in order to re-establish an intact tendon-bone interface. Arthroscopic and open repair of the rotator cuff has shown satisfactory outcomes for pain and shoulder function, as well as success rate, defined by avoiding additional surgery, of 94% at five years and 83% at 10 years, with significantly improved post-operative clinical outcomes. Immediate operative repair within three months has been proposed to result in better post-operative patient outcomes, as well as an earlier return to work and decreased costs. Patients undergoing repair within four months of the onset of symptoms can generally expect a good result, whereas repairs of full-thickness tears beyond one year of symptomatic
onset have demonstrated poorer results. Moosmayer et al demonstrated superior mean functional outcome scores in patients undergoing earlier surgical repair, compared with delayed or late surgery, but did not report the statistical significance of this difference, and both groups did not significantly differ in cuff integrity.

However, despite good clinical results for pain relief and ability to perform activities of daily living, both ultrasound and MRI findings have demonstrated a high rate of recurrent defects occurring in 20–94% of cases. Assessment of tendon integrity after tendon repair has shown mixed results. Harryman et al reported in a follow-up of 105 tendon repairs five years after open surgery, that a recurrent full-thickness defect was observed in 20% of patients who underwent repair for tears affecting the supraspinatus tendon alone, in 43% of patients who underwent repair for tears affecting the supraspinatus and infraspinatus tendons, and in 68% of patients who underwent repair for three tendon tears. Patients with an intact rotator cuff at post-operative follow-up demonstrated better function and shoulder range of motion than those with a tear recurrence, while the size of the recurrent defect was negatively correlated to the functional outcome. Similar results have been reported for mini-open and arthroscopic repairs. Furthermore, the American Academy of Orthopaedic Surgeons (AAOS) clinical practice guidelines on “Optimizing the Management of Rotator Cuff Problems” provided a consensus opinion that surgery should not be performed for asymptomatic rotator cuff tears, and provided a limited recommendation on rotator cuff repair as an option for patients with chronic, symptomatic full thickness tears. Given the aforementioned results, it would appear that conservative, non-surgical treatment should be considered as a viable alternative to surgical intervention.

NATURAL HISTORY OF ROTATOR CUFF TEARS AFTER CONSERVATIVE TREATMENT
Knowledge of the natural history of rotator cuff tears is important when making treatment decisions to achieve best outcomes for patients. Determining the appropriate course of treatment for rotator cuff tears should be based upon symptoms, whether the tear is full-thickness or partial-thickness and whether it is acute (traumatic), chronic (traumatic) or a combination of both (acute on chronic). As patients with rotator cuff tears present with a wide variety of symptoms, structural characteristics, and physical activity requirements, treatment approaches must be tailored individually. Although conservative treatment can be effective, information regarding who fails conservative treatment and who likely benefits from surgical repair is required to optimize patient outcomes. Characteristics of tears, as well as the individual level of functional deficit and/or patient-reported pain and symptoms that occur after a rotator cuff tear, may serve as a guideline as to what treatment direction to take, whether conservative rehabilitation or surgical repair. A treatment algorithm and indications for directing appropriate treatment for rotator cuff tears has been proposed (Figure 1). This includes three definitive patient groups, stratified via the natural history of partial-thickness and full-thickness tears, whether the tear is acute or chronic, and the prognostic factors for both conservative treatment and surgical treatment.

Group I
Patients over 60 years of age with chronic full-thickness rotator cuff tears, and individuals of any age with large or massive rotator cuff tears with chronic, irreversible rotator cuff changes already present, are thought to benefit from an initial course of conservative treatment. The healing potential in older adults with a rotator cuff tear is compromised and is impaired in this age group even after repair. Only 43% of patients over the age of 65 treated with arthroscopic rotator cuff repair of a full-thickness supraspinatus tear had evidence of healing at 18 months postoperatively compared with 86% of patients under 65. Due to the inconsistent outcomes of surgical repair in the >65 year age group, and the low risk associated with conservative treatment, a trial of non-operative intervention in this patient population is warranted. If non-operative treatment is unsuccessful, surgical treatment may be considered, but because healing is unlikely, the goal of surgery in elderly patients may be to convert a symptomatic tear to an asymptomatic tear.

Group II
Patients with either acute tears, or chronic full-thickness tears greater than 1–1.5cm who are younger
than 60 years old, are thought to benefit from early surgical intervention, due to significant risks for irreversible changes with non-operative treatment and a high likelihood of healing if repair is performed. It is generally recommended that surgical repair be performed instead of initial conservative treatment in active patients with acute tears after trauma. Early operative treatment appears to be better for rotator cuff tears with a sudden onset of symptoms and poor function for achievement of maximal return of shoulder function. Rotator cuff repairs are more successful in younger patients with a traumatic etiology as compared to those performed in an older cohort receiving surgery for atraumatic tears. Furthermore in a systematic review, Lazarides et al reported cuff tears in patients younger than age 40 are more commonly full-thickness tears and of traumatic origin, and typically respond well to surgery in terms of pain relief and self-reported outcomes post-operatively, due to good tendon and muscle quality at the time of repair. If left un repaired, over time the tear may enlarge, and the cuff may lose its elasticity, thus making the possibility of a later surgical repair more difficult. However, Bjornsson and colleagues determined that no differences existed with regard to tendon healing, pain, shoulder elevation, or functional outcomes whether an acute tear was fixed within three months of injury as compared to within three weeks.

It is well accepted that many patients with an atraumatic full-thickness rotator cuff tear will respond well to conservative treatment in the short term. Conservative treatment may be the preferred treatment because of advanced patient age, socioeconomic issues, and medical comorbidities. However, a question remains as to how to appropriately direct a younger (< 60 - 65 years), more active patient with a reparable full-thickness cuff tear, whether symptomatic or not. However, early surgical management in “young patients” with significantly sized, full-thickness tears (>1–1.5 cm) without chronic muscle changes should be considered because of the high risk for tear enlargement and progression over time. Safran et al and Maman et al followed subjects with conservatively treated symptomatic tears and independently noted the risk of tear progression to be between 19% and 49% at a follow-up duration of eighteen to thirty months. Safran et al evaluated 51 patients 60 years of age or younger who were treated non-operatively for a symptomatic full-thickness rotator cuff tear. At an average of 29 months’ follow-up, the investigators found an almost identical 49% of tears increased in size (>5 mm). Pain at follow-up was the only factor correlated

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**Figure 1. Treatment algorithm for pathology of the rotator cuff. Information derived from Tashjian et al.**

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with tear progression (56% with pain vs 25% without pain). Maman et al. evaluated 33 patients with full-thickness symptomatic rotator cuff tears and determined 52% progressed in tear size at an average of 24 months follow-up. Tear progression was more likely after 18 months (50%) compared with before the 18 month time frame (19%). Furthermore, patients older than 60 years and presence of rotator cuff fatty infiltration correlated with tear progression. From these studies, it is evident that there is a significant risk for tear progression in non-operatively treated symptomatic full-thickness tears with approximately 50% progressing at an average of two years.

**Group III**

Prolonged exercise rehabilitation and non-operative treatment should be considered in patients with rotator cuff tendinopathies, partial-thickness tears, and potentially small full-thickness tears, due to the limited risk for irreversible, chronic rotator cuff changes. Smaller symptomatic full-thickness tears have been shown to have a slower rate of progression, similar to partial-thickness tears, and can be considered for conservative management due to the limited risk for rapid tear progression. Although healing has not been shown to occur with partial tears without repair, significant improvements in functional outcomes have been shown with conservative treatment, as well as a slow, small risk for tear progression. Mall et al. evaluated 30 asymptomatic partial-thickness rotator cuff tears. At a two-year follow-up, 20 of the patients with asymptomatic tears that remained asymptomatic were compared with 10 patients with tears that became symptomatic. Ultrasound was performed at follow-up to evaluate for tear progression. Of those tears that remained asymptomatic, none progressed to a full-thickness tear. In the 10 patients whose tears became symptomatic, 40% progressed to a full-thickness tear. Pain was highly correlated with tear progression in asymptomatic partial-thickness tears and, therefore, can be used as a warning sign of enlargement and that further evaluation is warranted, such as follow-up imaging.

Maman and colleagues evaluated 30 patients with symptomatic partial-thickness rotator cuff tears at an average of 24 months with an MRI. These investigators found only 10% of symptomatic partial-thickness tears progressed in size (>5 mm), which is significantly less than the 50% progression reported in the same study for symptomatic full-thickness tears. The location of the tear had no effect on tear progression. This data suggests that tear progression of symptomatic partial-thickness tears occurs at a significantly reduced rate compared with symptomatic full-thickness tears; therefore, an initial conservative treatment approach is reasonable due to a decreased risk for tear progression. Furthermore, Fucentese et al. reported on the natural history of symptomatic isolated full-thickness supraspinatus tears in 24 patients with a mean age of 54 years. These patients had an average initial tear size of 1.6 cm and were re-evaluated at a mean of 3.5 years after non-operative treatment. Overall, there was no increase in the average tear size at follow-up and only 25% demonstrated tear progression. This is in contrast to the 50% tear progression reported by Maman et al. and Safran et al. Furthermore, the tear progression that occurred did not affect the reparability of these tears. This suggests that in small, full-thickness tears (<1–1.5 cm), initial observation and conservative management may be reasonable even in young patients, due to a low risk for tear progression (25%) unlike in larger tears, as shown by previous studies, which have a higher risk (approximately 50%) for tear enlargement.

**EVIDENCE FOR CONSERVATIVE MANAGEMENT IN ROTATOR CUFF TEARS**

Conservative treatment, including exercise therapy, is often offered as an initial management approach for patients with full thickness rotator cuff tears. Remarkably, it has been observed in patients whose repairs fail after surgical repair, that reported satisfaction levels and clinical outcome scores are similar to those with intact repairs. The authors of this study suggest that the reason for these findings is that because most of the patients in these studies engaged in some form of structured post-operative physical therapy, that it is possible that the post-operative rehabilitation is more responsible for the improvements in outcome. The primary objectives of non-operative management of a rotator cuff tear are to decrease pain, increase function and enhance activities of daily living (while mitigating potential long term adverse outcomes). Until recently, insufficient evidence existed justifying the need and importance for conservative management.
of rotator cuff tears. While the AAOS 2012 guidelines found inconclusive evidence to provide a recommendation for exercise as a treatment for rotator cuff tears, more recent studies relating to the progression of rotator cuff tendinopathy and tearing, as well as the results of surgical and non-surgical management, have provided sound rationale for exercise therapy in treating rotator cuff tears as an initial alternative to surgery. The Moon Shoulder Group demonstrated significant improvements in patient-reported outcomes and a low rate of surgery after physical therapy in the treatment of atraumatic full thickness rotator cuff tears. The study followed 381 patients (mean age 62 years, range 31-90) with atraumatic full-thickness tears of the rotator cuff, for a minimum of two years. Patients performed 6-12 weeks of non-operative physical therapy focusing on basic rotator cuff strengthening and shoulder mobility. Six weeks into the intervention, patients were assessed and 9% chose to have rotator cuff repair surgery. At 12 weeks, patients were again evaluated resulting in an additional 6% electing surgery. In total, 26% of patients decided to have surgery by the two-year follow-up. Analysis revealed that most patients will elect to undergo surgery in the first 12 weeks; however, if a patient does not choose to have surgery within the first 12-weeks of non-operative rehabilitation, they are unlikely to require surgery for up to two years.

Goldberg et al documented the functional outcome in a consecutive series of 46 patients with full-thickness rotator cuff tears who underwent conservative treatment and follow-up for at least one year. Treatment consisted only of patient education and a home program of gentle stretching and strengthening. Almost 60% of patients experienced improvement in general health and physical function scores, while 30% experienced worsening, and 11% remained unchanged. Two factors of the Simple Shoulder Test (the ability to sleep on the affected side and the ability to place the hand behind the head) improved significantly, whereas other components were not significantly improved. While these results demonstrate encouraging outcomes and suggest the effectiveness of exercise as treatment for cuff tears, it must be noted that there was no comparative cohort who underwent surgery in this study. A recent study by Kukkonen et al compared three different methods of treating symptomatic non-traumatic tears of the supraspinatus tendon in patients greater than 55 years of age. These patients either received physical therapy only, combined acromioplasty and physical therapy, or combined rotator cuff repair, acromioplasty and physical therapy. Of the 167 shoulders evaluated at one year, no differences were reported between any of the groups. Operative treatment was no better than conservative therapy with regard to management of non-traumatic supraspinatus tears, suggesting conservative treatment may be a worthy primary treatment method.

Moosmayer et al compared non-operative treatment to surgical repair of rotator cuff tears less than 3cm in size. In this study, patient-reported clinical outcomes were significantly better at 12 months in the surgery group; however, of the 51 patients randomized to the therapy group, only nine patients (17%) failed treatment and elected to have surgery. At five years, another three patients elected to have surgery, meanwhile the sonographic five-year follow-up of 38 tears treated with physiotherapy alone showed tear size increases of >5 mm in 37% of tears which was associated with an inferior outcome. Moosmayer et al in another study, observed the natural history of 50 patients with asymptomatic rotator cuff tears for three years. Eighteen tears developed symptoms during the period, and comparisons were made between tears that developed symptoms and those that did not. Their results showed a significant increase in the mean tear size, a higher progression rate of muscle atrophy, a significant rate of fatty degeneration, and a higher rate of pathology of the long head of the biceps tendon in the symptomatic group in comparison to patients with no clinical problems. These findings suggest that while non-operative treatment programs and patient education may be a viable initial option and alternative to surgery for many patients, tear size progression and structural deterioration over time may occur, predisposing these patients to symptom recurrence and functional depreciation. This emphasizes the importance of ongoing monitoring and surveillance.

**PROGNOSTIC FACTORS**

Itoi proposed that those pursuing conservative treatment should consider both the potential responsiveness of the specific patient to conservative treatment as well as the potential for symptom recurrence. Better understanding of who will, or will not, respond
well to conservative treatment prior to embarking on a course of conservative rehabilitation is of benefit to both the clinician and the patient. Some authors have described pertinent factors related to a successful outcome following conservative treatment for full-thickness rotator cuff tears. Itoi and Tabata have previously demonstrated that patients who responded well to conservative therapy exhibited good range of motion and abduction strength at initial examination. As mentioned previously, tears spreading into the posterior cuff disrupt the balance of muscular forces, impacting GHJ stability and affecting optimal function. Restricted range of motion in external rotation and tears extending from the supraspinatus to the infraspinatus tendon negatively affect the outcome following conservative treatment. Tanaka et al. identified four factors that appeared to correlate well with a successful outcome following conservative treatment: 1) a preserved range of motion in external rotation (>52 degrees); 2) negative impingement signs; 3) little or no atrophy of the supraspinatus muscle, and; 4) a preserved intramuscular tendon of the supraspinatus. Treatment was successful in 87% of cases who presented with at least three of these four factors, suggesting that appropriate identification of these factors and patient stratification may be useful in selecting patients who will best respond to conservative treatment.

Currently, the duration of shoulder symptoms is used as an indication for the surgical treatment of full-thickness rotator cuff tears. Also, an increased duration of a full-thickness rotator cuff tear may contribute to increased tear size, fatty atrophy of the rotator cuff muscle and/or reduced active motion. In a study on atraumatic, chronic rotator cuff tears by the Moon Shoulder Group, no correlations were observed between the duration of symptoms and features of rotator cuff disease, including severity of the rotator cuff tear and muscle atrophy as measured by MRI, patient-reported pain, strength, range of motion and/or general wellbeing. This research would suggest that using duration of symptoms might not be the best clinical feature when deciding an appropriate treatment approach for patients with atraumatic full-thickness rotator cuff tears. A commonly held view is that patients with chronic rotator cuff tears may develop symptoms when they are more active, or that a higher activity level contributes to the development of rotator cuff lesions. In patients electing initial non-operative treatment, Brophy et al demonstrated that while shoulder activity level is correlated with age and gender in patients with symptomatic, atraumatic rotator cuff tears, it does not correlate with the size or severity of the tear, suggesting it may be possible that increased activity helps patients develop compensatory kinematics and strength, which may prevent or minimize symptoms.

The influence of tear size on the success of conservative management is not known. Bartolozzi et al undertook a study of patients managed conservatively with symptomatic rotator cuff disease, and identified that full-thickness tears greater than 1 cm² combined with symptoms persisting more than one year, and functional impairment and weakness were associated with a worse outcome. Some tears continued to increase in size, whereas many others remained dormant and did not show signs of propagation. Those that did increase in size typically did so gradually, with only a minority (18-49%) enlarging >5 mm in three years of surveillance. Large (3–5 cm) and massive (>5 cm) full-thickness rotator cuff tears generally benefitted from surgical intervention. Nevertheless, some patients with massive tears reported functional and pain improvement with conservative treatment.

**EXERCISE REHABILITATION PROGRAMS**

The primary aim in treating a rotator cuff tear through conservative management is to reduce pain and improve function, and exercise rehabilitation is usually the cornerstone of this conservative management plan. Based on the available literature and the authors’ clinical experience, a comprehensive exercise program for the conservative management of rotator cuff tears has been provided (Appendix 1). In a systematic review of conservative treatments for rotator cuff tendinopathy undertaken by Littlewood et al, it was reported that exercise, whether completed at home or in a clinical setting, offered superior outcomes over no treatment or placebo, and did not differ in outcomes compared to surgery or multi-modal physiotherapy. This suggests that the exercise component of physical therapy is fundamental in the treatment of these tears, and most exercise protocols should demonstrate
clinically important change in patient-reported outcomes by 12 weeks. Similarly, in a systematic review, Ainsworth & Lewis reported that based on the available literature, exercise therapy when included as part of a treatment program, provided a beneficial effect in patients with symptomatic, full thickness rotator cuff tears. While it is unknown exactly why exercise was beneficial, they postulated that the effect of exercise may be multi-factorial. This may include its potential influence on pain modulation, providing a therapeutic effect on the structurally damaged rotator cuff muscles and tendons, placebo, muscular compensation for deficient movement strategies, and reducing kinesiophobia and the patient’s uncertainty if the arm should be moved. In addition, the term “mechanotherapy” has been coined to describe how controlled loading of tendons might stimulate tissue repair and remodeling. It is proposed that cells can respond to mechanical stimuli and convert the stimulus into a cellular response to promote tendon healing.

The goal of exercise as part of the physical therapy regime is to correct modifiable physical impairments thought to contribute to pain and dysfunction, rather than to treat the pathology per se. While the pathology of shoulder impingement syndrome and rotator cuff tears differ, the clinical presentation of both pathologies remains the same. Symptomatic rotator cuff tears are generally characterized clinically by pain with abduction (painful arc), as well as physical impairments including rotator cuff and scapular muscular weakness and dysfunction, tightness of the posterior capsule and other soft tissues, and postural abnormalities. Thorough patient assessment including inspection and palpation, assessment of range of motion and strength, and provocative shoulder testing for possible impingement syndrome and GHJ instability are all essential to individually tailor an appropriate exercise intervention. The neck and the elbow should also be examined to exclude the possibility that the reported shoulder pain is referred from a pathologic condition in either of these regions. Restoration of full, pain-free range of motion, flexibility, muscle balance, and scapulothoracic and glenohumeral muscular control and stability, are all important goals of the rehabilitation. Initially, patients should be well educated on provocative postures and movements such as reaching overhead, and appropriate advice and re-training be undertaken in avoiding or minimizing the occurrence of any aggravating activities. Exercises to improve shoulder girdle and GHJ range of motion are generally required to facilitate optimal motor patterning. Pendulum exercises (Figure 2) are effective in improving GHJ motion, initiated passively though progressing as tolerated toward active-assisted exercises, which are commonly performed with a bar or wand (3A and 3B) and the assistance of the uninvolved arm (Figure 4A and 4B).

It is well accepted that training and educating patients on improving scapular stability, proper neuromuscular control of shoulder girdle and thoracic posture is essential in a well designed rotator cuff exercise program. Potential contributing mechanisms to abnormal scapular kinematics include pain, soft tissue tightness, altered muscle activation or strength imbalances, muscle fatigue, and thoracic posture. Therefore, before beginning a strengthening program, it is important to identify muscles which appear tight or short, and ensure flexibility is restored. Tightness of the pectoralis minor and posterior glenohumeral capsular stiffness has been described in relation to abnormal scapular position. Increased scapular internal rotation, as well as increased anterior tilting, has been
Altered scapulohumeral rhythm, due to either fatigue or weakness of the scapular stabilizers, can induce shoulder dysfunction with an associated decrease in decreased GHJ internal rotation range of motion and anterior tilting is often observed in shoulder pathologies. 

Exercises that stretch the posterior cuff (Figure 5) and pectoralis minor (Figure 6), and reduce upper trapezius activation, are recommended to improve soft tissue tightness and allow for optimal scapular motion.
The muscles acting as scapular stabilizers ensure the scapula remains a stable basis from which the rotator cuff muscles can act, and adjust the glenoid fossa in relation to the humeral head during upper limb movements.\textsuperscript{94,95} In patients exhibiting rotator cuff tears and/or subacromial impingement, altered muscular activity or strength, and changes in the timing properties of the serratus anterior the upper, middle and lower portions of the trapezius are frequently observed.\textsuperscript{89,96} Specifically, it has been consistently shown that decreased serratus anterior strength, hyperactivity and early activation of upper trapezius, and decreased activity and late activation of middle and lower trapezius are present in patients with shoulder pain and pathology.\textsuperscript{89,97} Rehabilitation exercises addressing these altered shoulder complex kinematics to better stabilize and synchronize scapular movements, can increase the capacity of the rotator cuff muscles to stabilize the glenohumeral joint.\textsuperscript{98}

Exercise rehabilitation programs aimed at restoring scapulohumeral rhythm have frequently targeted the serratus anterior, middle and lower trapezius, while reducing the muscle activity of upper trapezius to enhance neuromuscular control and synchronised movement during elevation. A moderate level of muscle activation is adequate to retrain neuromuscular control for scapula and glenohumeral musculature, especially in the initial phases of rehabilitation.\textsuperscript{99} In the early stages of rehabilitation, conscious neuromuscular control of the scapular muscles may be necessary to improve proprioception and to normalize the scapular resting position, followed by advanced neuromuscular control and scapular co-contraction, in both open and closed-chain settings.\textsuperscript{89} Kibler et al\textsuperscript{99} identified specific exercises for scapular control in the early to middle phases of shoulder rehabilitation, including the ‘low row’ (Figure 7), ‘lawnmower’ and ‘robbery’ exercises, which activate the key scapular-stabilizing muscles, including the rhomboid, without putting high demands on the GHJ joint. Specific strengthening exercises of the serratus anterior, typically include ‘supine pro-tractions’ and ‘wall push-up’ exercises, and are be beneficial in the early stages of rehabilitation\textsuperscript{89} while dynamic hugs and push-up varieties are commonly utilized in later stages of rehabilitation.\textsuperscript{100,101} Cools et al\textsuperscript{102} suggested exercises that promote high middle and lower trapezius activation and minimal upper trapezius participation (i.e a high middle/lower to upper trapezius ratio), are preferable in shoulder complex rehabilitation programs. These exercises include side lying external rotation (Figure 8), side

Figure 5. Cross-body stretch for the posterior capsule

Figure 6. Anterior capsule / pectoralis minor stretch using a door-frame
lying forward flexion, prone horizontal abduction with external rotation and prone extension (Figure 9), which also show high EMG activity in the rotator cuff muscles, particularly the infraspinatus and teres minor.103-105

Understanding the impact that cuff tears have on shoulder complex function and muscle activation patterns can contribute to designing a restorative exercise rehabilitation program. Strengthening of the rotator cuff muscles is important to provide accurate positioning and stabilization of the humeral head in the glenoid fossa, preventing excessive elevation of the humerus, which may cause impingement and compression of the tendon against the coracoacromial arch. Translation of the humeral head relative to the glenoid fossa occurs in healthy shoulders and is maintained within normal limits by the coordinated activity of the rotator cuff muscles.106 However, when the rotator cuff is torn, this disrupts the glenohumeral fulcrum, leading to abnormal superior translation of the humeral head on the glenoid fossa during arm elevation as the destabilizing force generated by the deltoid muscle is unchallenged.107,108 Furthermore, the torn supraspinatus can no longer develop an abduction torque at the GHJ; therefore, the deltoid may be required to perform additional work in a compensatory manner during arm elevation.109 An EMG study by Hawkes et al,106 demonstrated the reorganization of muscle activation strategies that occur in the upper limb kinetic chain following a rotator cuff tear. Increased activity of the scapula stabilizers and elbow flexor muscles has been reported representing a tactic within proximal and distal segments to reduce demand on the GHJ. They specifically demonstrated increased activation of the latissimus dorsi and teres major muscles, as a partial compensation for the deficient rotator cuff by balancing the destabilizing forces of the deltoid. This has led to the hypothesis that alternative muscle activation strategies can compensate for the deficient rotator cuff to limit the superior migration of the humeral head and establish a stable glenohumeral fulcrum for arm movement.37,108-110

Figure 7. Low row exercise as described by Kibler et al99

Figure 8A and 8B. Side-lying external rotation
Strength-based exercises for rotator cuff tears should appropriately target the remaining intact cuff musculature, initiated with low load activities and progressing as patient comfort permits. In massive rotator cuff tears whereby the supraspinatus and infraspinatus are deficient, the teres minor becomes important in maintaining active external rotation, and should be a focus for the rehabilitation in massive cuff tears. The teres minor muscle provides 20% to 45% of the external rotation power to the glenohumeral joint and retains the power in large and massive tears involving the infraspinatus tendon, as it usually remains intact even in large or massive rotator cuff tears. Exercises that show high EMG activity in the rotator cuff muscles, and in particular the teres minor, include side-lying external rotation (Figure 8), external rotation at 0° and 90° of abduction, and prone external rotation in 90° of abduction.

Retraining and strengthening of the anterior deltoid has also been a focus for massive cuff tear patients. In a pilot study, Ainsworth et al proposed a progressive strengthening program for massive rotator cuff tear patients aimed at the anterior deltoid and teres minor muscles, and demonstrated improvements in pain and function after 12 weeks of training. The program was based upon the observation that patients with massive rotator cuff tears utilized the anterior portion of deltoid in order to achieve elevation without upward shearing of the humeral head. Patients progress from supine shoulder flexion (Figure 10), to inclined shoulder flexion (Figure 11) to upright shoulder flexion (Figure 12). Furthermore, the authors observed that patients who had active external rotation, fared better than those who struggled to activate lateral rotation, despite dysfunction of the infraspinatus, and hypothesized teres minor was recruited better in these patients in order to improve their external rotation function enough to enable the greater tuberosity of the humerus to clear the undersurface of the acromion during elevation. Ainsworth et al followed this up with a prospective randomized controlled trial, comparing outcomes between patients with diagnosed massive rotator cuff tears who underwent physiotherapy combined with a comprehensive exercise program, versus physiotherapy without exercise. The exercise program focused on active anterior deltoid strengthening, teres minor strengthening for active external rotation, scapular stability and control exercises, patient education, adaptation, proprioception, and a home exercise program. Both groups demonstrated an overall improvement; however, patients receiving exercise reported a greater and faster improvement compared to those who did not receive exercise. These results were supported by Levy et al, who found that a deltoid muscle rehabilitation regimen was effective in improving function and pain in 17 elderly patients with massive cuff tears, up to at least nine months after starting rehabilitation.

While efficacy of exercise has been demonstrated, optimal dosage remains unknown. Studies reporting favorable outcomes with exercise in people complaining of shoulder pain, generally utilized three
sets of 10-15 repetitions completed twice per day as the recommended dose.\textsuperscript{3,95,115,116} It is also recommended that exercise be performed and progressed in the complete absence of pain, as well as during minor discomfort, as recommended by the pain monitoring model,\textsuperscript{117} which has been successfully used in earlier studies that included patients with tendinopathy to ensure that the exercise treatment was well tolerated by the patients.\textsuperscript{95,117,118} It has been reported that an exercise intervention should be maintained for at least 12 weeks in order to demonstrate clinically significant outcomes,\textsuperscript{119} though uncertainty exists over how long to undertake conservative care before seeking a surgical opinion. Recommendations have ranged from 3-18 months.\textsuperscript{20,82,120}

**SUMMARY**

Tendinopathy and tears of the rotator cuff are age-related and commonly degenerative pathologies that can impact an individual's quality of life, and lead to surgical intervention. The economic and social burden associated with symptomatic rotator cuff tears is substantial, and population trends indicate this burden will progressively worsen. The role
of exercise in treating rotator cuff tears has become increasingly popular as a means to treat and manage partial and full-thickness tears of the rotator cuff, by addressing weakness and functional deficits that are commonly present in patients with symptomatic shoulders. Prolonged exercise rehabilitation and non-operative treatment should be considered in patients with rotator cuff tendinopathies, partial-thickness tears and potentially small full-thickness tears. Younger patients with acute tears >1cm will likely respond well to operative intervention, while older patients (> 65 years) with chronic, full-thickness tears and associated muscle atrophy and fatty infiltration will not, and instead respond better to an initial course of exercise rehabilitation. According to reports in the literature, conservative treatment is effective in 73–80% of patients; however, not all patients will respond favorably or quickly. When opting for conservative treatment, it is important to understand that the responsiveness of patients and symptom recurrence will determine the potential for a successful outcome of exercise rehabilitation.

REFERENCES
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Figure 12A and 12B. Standing shoulder flexion


90. Borich MR, Bright JM, Lorello DJ, Cieminski GJ, Buysman T, Ludewig PM. Scapular angular


115. Bernhardsson S, Klintberg IH, Wendt GK. Evaluation of an exercise concept focusing on eccentric


## APPENDIX 1

Evidence-based exercise protocol for the conservative management of rotator cuff tears.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Goals</th>
<th>Exercises</th>
<th>Dose</th>
<th>Progression</th>
</tr>
</thead>
</table>
| Range of Motion (ROM)       | 1. Improve glenohumeral motions (forward flexion, abduction & external rotation)  
                            2. Improve shoulder and thoracic posture | • Passive ROM (PROM)    
                             • Forward flexion, internal / external rotation    
                             • Pendulum (Figure 2)    
                             • Posture    
                             • Postural education    
                             • Scapula setting exercises    
                             • Active-assisted ROM (AAROM)    
                             • Wand exercises: elevation, abduction, adduction, internal / external rotation (Figure 3)    
                             • Pulley-assisted elevation    
                             • Active ROM (AROM)    
                             • Wall slides | 3 x 15 reps, daily | • ROM should begin with PROM and pendulum exercises, progressing to AAROM & AROM as comfort dictates |
| Flexibility                 | 1. Improve flexibility and reduce tightness of anterior and posterior capsule | • Anterior capsule (pectoralis minor) stretch     
                             • Supine bear hugs     
                             • Door frame stretch (Figure 6)     
                             • Posterior capsule stretch     
                             • Cross-body stretch (Figure 5)     
                             • Towel stretch     
                             • Upper trapezius stretch | 5 x 30sec stretches, daily | N/A |
| Strengthening               | 1. Improve strength of the scapular stabilizing muscles and dynamic scapular control  
                            2. Improve strength of the anterior deltoïd for shoulder elevation  
                            3. Improve active external rotation strength | • Isometric low rows (Figure 7)     
                             • Scapula retraction / rows     
                             • Prone scapula retractions (squeezes), prone shoulder extension (Figure 9)     
                             • Bent over rows, seated / standing (elastic resistance)     
                             • Scapula protractors / presses     
                             • Supine scapula protractors     
                             • Upright wall scapula protractors / retraction, wall push-ups     
                             • Quadruped scapula protractors     
                             • Standing scapula presses with elastic resistance     
                             • Anterior deltoïd strengthening     
                             • Isometric deltoïd contractions     
                             • Shoulder flexion: supine (Figure 10), inverted (Figure 11) and standing (Figure 12)     
                             • External Rotation     
                             • Standing, 0° abduction with elastic resistance     
                             • Side lying with dumbbell (Figure 8)     
                             • Internal Rotation     
                             • Standing, 0° abduction with elastic resistance     
                             • Side lying with dumbbell | 3 x 15 reps per exercise, 3 – 4 times per week | • Strengthening is undertaken within limits of pain.  
                                                                                           • Increase volume and load, as comfort, strength and tolerance dictate.  
                                                                                           • Patients exceeding appropriate discomfort level should reduce the level of resistance |
| Strengthening / proprioception (Advanced) | 1. Advance strengthening of the scapular stabilizers  
                                         2. Advance strengthening of the rotator cuff  
                                         3. Introduce work / sport-specific exercises | • Scapula protractors / presses     
                             • Upright rib ball push-ups, push-ups on ground     
                             • Standing cable press     
                             • Dynamic hug exercise     
                             • Scapula retractions / rows     
                             • Standing cable row     
                             • External Rotation     
                             • Seated & standing 90° abduction (dumbbell & elastic resistance)     
                             • External rotation in 90° prone horizontal abduction     
                             • Internal Rotation     
                             • Standing, 90° abduction (elastic resistance) | 3 x 15 reps per exercise, 3 – 4 times per week | • Strengthening is undertaken within limits of pain.  
                                                                                           • Increase volume and load, as comfort, strength and tolerance dictate.  
                                                                                           • Patients exceeding appropriate discomfort level should reduce the level of resistance |
ABSTRACT

Background & Purpose: Rugby requires unique demands from its players. Those involved in rehabilitation and care of these athletes must possess an understanding of both the game and various positions. There have been numerous reports focusing on the physiological demands and biomechanical analyses of various components of gameplay, but no specific progression has been developed to assist clinicians assessing the readiness to return of a player after injury. The purpose of this clinical commentary is to outline testing components, general gameplay guidelines, movement progressions, and sport and position-specific progressions related to rugby gameplay following a lower extremity injury.

Description of Topic: This commentary provides a recommended progression for clinical use for use in a return to rugby program. It includes metabolic considerations, advanced strengthening exercises, agility exercises, and incorporation of drills specific to the sport of rugby that may be performed with the clinician or with assistance from team members. This progression also includes testing parameters for each phase and guidance for clinicians regarding the ability to gauge readiness to return to sport.

Discussion: It is essential that an athlete returning to the sport of rugby undertake a guided, graduated return to sport progression to ensure safety and to decrease the risk of re-injury. This proposed return to sport progression outlines key parameters for both the sport as a whole and for various specific positions.

Level of Evidence: Level 5 – Clinical Commentary, Review of Literature

Keywords: Positional demands, rehabilitation, return to play, rugby
INTRODUCTION
Clinicians involved in the care of rugby players must not only be aware of the underlying pathology of the injured site, but also the specific physiological demands required for successful play in this sport. In addition, the various positions in the game of rugby each necessitate a unique skill set and metabolic requirement for effective performance in the domains of speed, agility, power, and endurance. Returning an athlete to sport requires a multidisciplinary approach, often involving surgeons, other physicians, physical therapists, athletic trainers, strength and performance coaches, nutritionists, and psychologists. As a rehabilitation specialist, knowledge of each rugby position is essential in order to fully prepare the player for successful reintegration into competition.

Time missed from match or training due to injury has been reported to range from two hours\(^1\) to over 262 hours per 1000 player hours.\(^2\) The lower extremity is the most common site of injury, with 41% to 55% of all injuries in rugby sustained in the lower extremity.\(^3\) Medial collateral ligament (MCL) and anterior cruciate ligament (ACL) injuries have been reported to result in the greatest proportion of absence from play.\(^4\) Lateral ankle sprains are the most common injury occurring at the ankle joint.\(^5,6\) Noncontact injuries account for 57% of those sustained during training,\(^6\) although this proportion decreases during match play.\(^5\) Noncontact injuries of the knee have been reported to be as high as 22% of all match related injuries.\(^4\) Hamstring muscle injuries account for the highest number of noncontact injuries overall.\(^5,6\)

The purpose of this clinical commentary is to outline testing components, general gameplay guidelines, movement progressions, and sport and position-specific progressions related to rugby gameplay following an injury to the lower extremity.

GENERAL GAMEPLAY
The sport of rugby is played with 15 members per team (8 forwards and 7 backs) on a 100 meter by 70 meter field with two try zones at either end that are 10 meters deep. A typical match duration is 80 minutes total with two 40 minute halves, as well as additional stoppage time as needed. Players may run in any direction as long as they do not use another player to block for them, which results in an infringement called obstruction.

Although the game clock is designed for continuous play, the sport of rugby is played primarily in bursts of varying duration that depends upon an assortment of factors, such as a player’s position and role in the game. Elite players reach peak speeds of 13.1-19.3 miles•hour\(^{-1}\) with the total distance covered by players in a match ranging from 3.9-4.5 miles.\(^44\) On average, players compete at a mean of 80-85% of their VO\(_2\) maximum and at approximately 88% of their maximal heart rate.\(^44\)

In general, backs cover greater total distances than forwards.\(^44\) However, flankers devote the most time of the forwards in the high and maximal intensity speed zones.\(^44\) Forwards sprint an average distance of 8.0 meters for an average duration of 1.1 seconds while backs sprint an average distance of 13.8 meters for an average duration of 1.8 seconds.\(^45\) Just as the sprint distances and durations vary, the metabolic demands between backs and forwards also differ. Due to their involvement in rucks, mauls, and scrums, forwards require an increased aerobic capacity to continue play following these events, even at a reduced pace. In contrast, backs perform in a more anaerobic environment as they alternate between bursts of speed followed by walking between various stops in play. Therefore, the work-to-rest ratio commonly used in training is typically 1:7 for forwards and 1:20 for backs.\(^46\)

REQUIREMENTS FOR RETURN TO RUGBY
After sustaining an injury to the lower extremity, the athlete progresses through the stages of healing and various fundamentals must be in place prior to examination for and consideration of return to sport. It is assumed that the athlete will demonstrate adequate progression in proper healing parameters, range of motion, and muscular strength as listed in Table 1 prior to progressing to any type of return to sport progression. Unilateral balance and strength training are usually addressed as early as possible to ensure movement normalization. Strength training may then be progressed to circuit training in order to promote a capacity for power endurance using a variety of training modalities, such as Olympic weightlifting,
traditional weight training, and other ancillary exercises. Neuromuscular compensations and deficits often persist following any lower extremity injury and typically require guided correction.7,8 Normalization of these deficits assists in decreasing the risk of a subsequent injury and the movement strategies obtained during this phase serve as the basis for progression through the later phases of rehabilitation.9,10

Pain frequently contributes to diminished strength and coordination output following an initial injury, which necessitates emphasis on neuromuscular control and strength during the initial phases of rehabilitation.11,12 Once the athlete has begun to develop sufficient strength, he or she may then begin to practice loading, landing, and deceleration mechanics. Neuromuscular control with these movement strategies are promoted using drills such as lunges, single limb squats, small bounding hops in the sagittal plane progressing to the frontal plane, and drop box landings. Verbal and visual feedback is vital to assist with the athlete’s success, and these cues have been proven to alter an athlete’s movement strategy.10,13,14 An anti-gravity treadmill or aquatic environment may assist in unloading the athlete’s weight while respecting physiological healing and decreasing the overall demand placed on the lower extremities.

Prior to the return to sport progression, a progressive running tolerance program on level surfaces should be initiated when appropriate. As the athlete begins to demonstrate improved strength and appropriate neuromuscular control, he or she may initiate more advanced strength training. These may include, but are not limited to, Olympic weightlifting derivatives, such as squats, deadlifts, power cleans, and Romanian deadlifts. It is also important to include triple extension strength, and power development, utilizing bungee cords or cables for increased time under tension.

The authors’ recommended testing elements for demonstration of movement normalization are contained in Table 2. The Y-Balance Test™ is a measurement of single limb balance and motor control, that has been validated in the literature, most notably with regards to injury risk assessment.15-17 The authors recommend the use of this test to ensure the returning athlete demonstrate the requisite single limb stability of at least 90% when compared to the contralateral lower extremity. The single leg bridge and single leg squat are other excellent assessments for core stability and appropriate gluteal musculature function and strength. Weakness in the core and hip muscle groups have been identified as risk factors for lower extremity injury risk.18-21 Altered

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**Table 1. Criteria for Initiation of Rugby Progression**

<table>
<thead>
<tr>
<th>Criteria for Initiation of Rugby Progression</th>
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<tbody>
<tr>
<td>Absence of swelling or joint effusion</td>
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<tr>
<td>Full, pain-free PROM and AROM symmetrical to contralateral extremity</td>
</tr>
<tr>
<td>Adequate baseline extremity and core strength</td>
</tr>
<tr>
<td>1. ≥4/5 strength of affected area via MMT or HHD</td>
</tr>
<tr>
<td>2. Appropriate functional tests (select those applicable to appropriate area)</td>
</tr>
<tr>
<td>a. 1 minute 8 inch box heel tap comparison</td>
</tr>
<tr>
<td>b. 1 minute 8 inch box step up comparison</td>
</tr>
<tr>
<td>c. 1 minute calf raise comparison</td>
</tr>
<tr>
<td>The injured lower extremity should be within 85% of the uninjured limb</td>
</tr>
</tbody>
</table>

Key: *PROM* = passive range of motion; *AROM* = active range of motion; *MMT* = manual muscle testing; *HHD* = hand held dynamometry

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**Table 2. Testing Elements for Demonstration of Movement Normalization**

<table>
<thead>
<tr>
<th>Y-Balance Test™</th>
</tr>
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<tbody>
<tr>
<td>• &lt;90% difference between the contralateral lower extremity for each movement</td>
</tr>
<tr>
<td>5 single leg bridges with a 10 second isometric hold performed at the top of the movement</td>
</tr>
<tr>
<td>• No presence of trunk rotation or hamstring substitution</td>
</tr>
<tr>
<td>1 minute single leg squats to depth of 60-70 degrees of knee flexion</td>
</tr>
<tr>
<td>• No presence of valgus collapse</td>
</tr>
<tr>
<td>• Appropriate posterior chain recruitment</td>
</tr>
<tr>
<td>• Sufficient trunk control and balance</td>
</tr>
</tbody>
</table>

Running tolerance |
| • Able to run >20 minutes without symptom provocation or effusion |
lower extremity mechanics\textsuperscript{18,22} due to the effects of proximal lower extremity muscle weakness have been significantly correlated with lower extremity pathologies such as iliobibial band syndrome,\textsuperscript{23} patellofemoral pain syndrome,\textsuperscript{24-26} and ankle sprains.\textsuperscript{27} In order to identify gluteal muscle activation deficits, a single leg bridge can be a useful assessment. During a single leg bridge, the athlete often demonstrates a functional gluteal deficit with overcompensation from the hamstring muscle group. In addition, trunk rotation or a contralateral pelvic drop during a single leg bridge can assist with identification of deficits in core stability. The single leg squat has been proven to identify core strength\textsuperscript{26,28} and has been correlated with landing, running, and cutting tasks.\textsuperscript{29-32} Athletes often demonstrate increased trunk displacement, contralateral pelvic drop, hip adduction, and valgus collapse\textsuperscript{26,33-38} during this maneuver, which are indicative of deficits in postural stability and proximal hip muscle function.\textsuperscript{26,38-42} In addition, the single leg squat test has been utilized to screen for residual deficits in core stability and hip abduction strength in baseball players returning from shoulder injury.\textsuperscript{40,43}

As the athlete continues to develop strength and power capacity, a progressive plyometric-based program should be incorporated. It is imperative that the athlete demonstrate appropriate eccentric control with landing or deceleration during various drills throughout treatment sessions. It has been well documented that lower extremity biomechanics and movement alterations have been correlated to injuries to the ACL.\textsuperscript{45-56} In a study analyzing biomechanical measures during landing, Paterno et al\textsuperscript{9} determined four factors that predispose an athlete to a second ACL injury in those who had previously undergone an ACL reconstruction. These predictive factors included increased knee valgus, asymmetry in knee extensor moment during initial contact, poor single limb postural stability, and decreased contralateral hip rotation strength (assessed using moment data). Clinicians should monitor players for these elements when performing plyometric interventions during rehabilitation. Plyometric activities have been shown to improve sprinting\textsuperscript{57} and agility\textsuperscript{58} performance. Vertical progressions should include depth jumps progressing to tuck jumps (adding rotation when appropriate) and box jumps of varying heights, with the athlete eventually progressing to single limb drills. Horizontal progressions should include line hops, slide board exercises, alternating single limb bounding, as well as single limb single and triple hops crossing over through multiple planes. During these horizontal progressions, the emphasis should be on achieving horizontal rather than vertical displacement in preparation for change of direction and agility drills.\textsuperscript{59}

Change of direction and agility are important facets of rugby in order to evade tacklers and create an open field of play.\textsuperscript{59} An athlete's agility performance is strongly influenced by the ability to rapidly decelerate and reaccelerate while adjusting his or her momentum to either pursue or elude opponents.\textsuperscript{60} Team sport athletes are typically involved in change of direction events during sprints of approximately five meters.\textsuperscript{61} More specifically, Meir et al\textsuperscript{62} reported that rugby players typically come into contact with an opposing player at distances of 10 meters. Therefore, Delaney et al\textsuperscript{63} utilized the 505 test\textsuperscript{64} to analyze the contributing factors to change of direction ability of male professional rugby players. The authors concluded that the 505 test performed on the athletes’ dominant lower extremity was significantly correlated with the athletes’ linear sprint speed over a 40 meter distance. Performance of the 505 test on the non-dominant lower extremity was dependent upon relative strength and relative power (determined by a ratio of the player’s three repetition maximum back squat and a 40 kilogram barbell squat jump, respectively, divided by the player's body mass). Other researchers who have analyzed change of direction and ability in rugby players have utilized tests involving thirty to forty-five degree cuts,\textsuperscript{59,65,66} which have been studied previously in observance with game situations.\textsuperscript{60,67-73}

During change of direction maneuvers, an athlete uses their plant leg to decelerate his or her body from linear running prior to initiating the change of direction task. The athlete's push off leg then initiates acceleration of the body into the new desired direction.\textsuperscript{59} In a comparison of cutting technique performance of semiprofessional rugby players, Green et al\textsuperscript{59} calculated an average transition time from initial contact of the plant leg to toe off of the push off leg to be significantly shorter in starters versus nonstart-
ers. McLean et al\textsuperscript{68} investigated the biomechanics of sidestep cutting using three-dimensional motion and ground reaction force analysis. After initial contact, anterior and inferior forces of the trunk produces average hip and knee flexion angles of 48.7 and 60.2 degrees, respectively, as well as an average knee valgus angle of 13.2 degrees. These measurements are similar to those calculations previously reported in the literature.\textsuperscript{69,71} During the addition of a simulated defensive opponent, athletes demonstrated an increase in hip flexion, knee flexion, and knee valgus angles.\textsuperscript{68}

It is imperative that the athlete demonstrates proper technique during agility drills, such as planting with the outside leg, appropriate amount of knee flexion as mentioned previously, leaning into the cut, and full triple extension of the push off leg. Previous authors have reported that a more upright position with increased hip and knee extension at initial contact may correlate to an increased risk of lower extremity injury and may also hinder the athlete's proficiency in generating force to improve the resultant stride velocity after the change of direction task.\textsuperscript{68,74} The rehabilitating player should also begin to integrate movements that focus on footwork skill, such as agility ladder drills. As the athlete's footwork begins to return to normal, he or she may then progress to more challenging agility movements, such as the T drill\textsuperscript{75}, box drills, and reactive linear and diagonal drills. A progression from proactive to reactive drills should be utilized as the intention of this progression is to prepare the athlete for reintegration into practice activities and noncontact drills with the team. Various testing elements are also useful to aid the clinician's decision to reintegrate the athlete back to practice, such as hop testing,\textsuperscript{76} 40 meter sprints from the upright, prone, and rolling positions, as well as the L run\textsuperscript{77} and the Pro Agility Test.\textsuperscript{77}

Once the athlete demonstrates the requisite requirements in preparation for returning to the practice field, he or she should begin a series of rugby-specific practice drills. To the authors’ knowledge, there is no available evidence for the following drill progression and the following are the authors' recommendations based off similar research published for athletes of similar sports\textsuperscript{78,79} that have been adapted for the sport of rugby. These drills are commonly performed in conjunction with the coaching staff while the rehabilitation specialist monitors the returning athlete for any symptom provocation, abnormal movement patterns, performance decline, and psychological factors. Controlled movements with a teammate should be performed initially, such as forward runs with lateral passes within a fixed distance interval (typically 10 meters) followed by diagonal runs and switch passes. The athlete should focus on completing accurate passes rather than maximal effort. During the sport of rugby, passes may be completed directly horizontally or behind the passing player. Once this is effectively demonstrated, the athlete may progress to reactive agility drills beginning with the recovering athlete emulating the movements and changes in the direction of a teammate within a boxed area. The athlete should begin with linear movements before progressing to diagonal and multi-planar movements. Once competence is demonstrated with reactive agility maneuvers, the clinician may then allow scrimmage situations beginning with small-sided games of touch rugby. Reintegration into competitive match play should be accomplished in small increments. Again, the athlete should be monitored for any symptom provocation, abnormal movement patterns, performance decline, and psychological factors. Progressions for other specific aspects of game play, such as lineouts, kicking, scrummaging, and tackling are covered in the next section of this commentary.

**POSITION SPECIFIC PROGRESSIONS**

**Lineout Progression**

The purpose of a lineout is to restart game play quickly, safely, and fairly after the ball has left the field of play. The lineout involves a throw-in of the rugby ball between two lines of players (one line from each team) spaced at one meter apart, usually at the exact place where the ball went out of play. The throw in a lineout is usually between 5 and 15 meters in distance\textsuperscript{80} and is normally executed overhead with two hands (with or without a step forward) with the ball being spun about its longitudinal axis (Figures 1a and 1b).\textsuperscript{80}

Once the athlete demonstrates the requisite requirements in preparation for returning to the practice field, he or she should begin a series of rugby-specific practice drills. To the authors’ knowledge, there is no available evidence for the following drill progression and the following are the authors' recommendations based off similar research published for athletes of similar sports\textsuperscript{78,79} that have been adapted for the sport of rugby. These drills are commonly performed in conjunction with the coaching staff while the rehabilitation specialist monitors the returning athlete for any symptom provocation, abnormal movement patterns, performance decline, and psychological factors. Controlled movements with a teammate should be performed initially, such as forward runs with lateral passes within a fixed distance interval (typically 10 meters) followed by diagonal runs and switch passes. The athlete should focus on completing accurate passes rather than maximal effort. During the sport of rugby, passes may be completed directly horizontally or behind the passing player. Once this is effectively demonstrated, the athlete may progress to reactive agility drills beginning with the recovering athlete emulating the movements and changes in the direction of a teammate within a boxed area. The athlete should begin with linear movements before progressing to diagonal and multi-planar movements. Once competence is demonstrated with reactive agility maneuvers, the clinician may then allow scrimmage situations beginning with small-sided games of touch rugby. Reintegration into competitive match play should be accomplished in small increments. Again, the athlete should be monitored for any symptom provocation, abnormal movement patterns, performance decline, and psychological factors. Progressions for other specific aspects of game play, such as lineouts, kicking, scrummaging, and tackling are covered in the next section of this commentary.
ball at a height of 3 to 3.5 meters. Initially, the weight of the jumper is usually shared equally during the lift, but then is transferred toward the rear lifter. Once the ball is caught, the lifter releases his or her teammate resulting in a landing, for the jumper, from a height of 1 to 1.5 meters.81 Each of the different positions in a lineout requires very different demands and varied stresses placed on the player’s body, requiring special attention during the middle and end phases of rehabilitation as the player prepares to return to game play.

Specific requirements for lineout drills will vary for lifters or props, jumpers (locks), and throwers (usually the hooker). For lifters or props, it is essential that they have full shoulder and elbow range of motion and strength. They must demonstrate the requisite core strength and control required to produce enough power to lift jumpers from the ground to a height of 1 to 1.5 meters.45,80,81 Jumpers (locks) must demonstrate excellent core strength and stability in an upright position, especially on unstable surfaces. They must also demonstrate the ability to safely land from a height of one meter with safe and quick transitions upon landing.45,80,81 Throwers must have full shoulder mobility and must demonstrate adequate core strength in order to produce power when throwing overhead. They also must demonstrate the ability to accurately throw the rugby ball to the jumper between 5 and 18 meters away.80 Specifically, the thrower must demonstrate adequate shoulder flexion, medial rotation, elbow flexion and supination, followed quickly by shoulder extension, lateral rotation, elbow extension, and pronation during the completion of the throw.80,81 This motion demands full glenohumeral and scapulothoracic motion, as well as adequate thoracic spine mobility, specifically thoracic extension.

**Lineout Drills**

**Lifters:** In order to adequately prepare lifters for the demands of a lineout, proper progression of strength and conditioning must be employed with a specific focus on power and triple extension drills. This can be accomplished via kettle bell swings and high-load lower extremity lifts including squats, deadlifts, snatches, cleans, and clean and jerk exercises. A useful drill for these players utilizes a tackle bag to mimic the weight and size of the jumper, ideally with the majority of weight at the top of the object being lifted.81

**Jumpers:** Jumpers have multiple roles in a lineout and will have different sport requirements that need to be addressed in the clinic prior to returning to full gameplay. In order to prepare jumpers for the landing aspect of a lineout, drills involving progressive drop jumps up to 1.5 meters high must be performed with good lumbopelvic, knee, and ankle control.81 These drills should also address landing on unstable surfaces and should incorporate quick transitions, such as landing followed by cutting or

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**Figure 1.** Lineout sequence, a) Two lines of players from each team are evenly spaced with the thrower preparing to execute an overhead throw, b) Jumpers are hoisted by their teammates in preparation to catch the ball as it is thrown directly down the center of the two lines.
sprinting immediately afterwards. Lastly, the drills should incorporate catching or deflecting the rugby ball followed by a safe landing from a height of 1.5 meters. Catching progressions should begin with chest level drills and then progress towards overhead catches and deflections. These drills should initially be performed on stable surfaces before transitioning to unstable surfaces in order to challenge core stability in a similar fashion to catching and/or deflecting the ball while being lifted. Drills should be progressed from proactive drills with a known pattern (such as ball toss to a rebounder) to reactive drills, which involve unknown patterns (such as perturbation training while catching and clinician throwing the ball in different positions and locations to stress reaction to stimulus). Core stability is another major focus during rehabilitation for preparation of a jumper in their return to safely performing lineouts. These drills should begin in the sagittal plane before incorporating exercises in the transverse plane. Drills should also include quick transitions from catching to throwing with arms overhead, beginning with stable and progressing towards increasingly unstable positions and surfaces. A typical progression of positions includes kneeling to half kneeling, then to standing, and finally to single leg stance.

Throwers: Players that may be placed in the throwing position for a lineout must demonstrate safe and effective lower extremity mechanics during a progressive throwing program. Throwing drills should start with chest passes then progress to overhead passes. Throwing should start with short distances and progress up to at least 18 meters. Target training should be incorporated to promote accuracy and proprioception. This can be accomplished with use of a target that is held at the approximate height of a jumper (approximately 3 to 3.5 meters high). A small medicine ball or weighted rugby ball can also be used for target training to gradually increase demands in a safe environment prior to implementing on-field drills.

Section testing elements for return to lineouts include the ability to perform all position-specific lineout requirements as detailed above. Tolerance to intensity should be evaluated by maximal effort in the clinic with drills that closely simulate the position played without symptom provocation, as well as full game play without symptom provocation.

Kicking Progression

Despite its fundamental role in the game of rugby, frequency and demands of kicking in the sport of rugby are poorly documented. Kicking is an essential skill for backs and must be addressed before the player is fully released to play. In the game of rugby, kicking (Figures 2a and 2b) can be performed out of hand, from a kicking tee (i.e. goal kick or place kick), or from the ground (i.e. drop goal). The goal or place kick can be performed toe end style (player approaches the ball straight on and kicks the ball using the toe of the boot) or instep style (player approaches the ball from an angle and kicks the ball with his/her instep). Game play begins with a kick off, either a place kick or a drop kick, from the center of the halfway line. The ball must travel at least 10 meters from the point of kickoff. A drop kick from the halfway line will also restart the game after a penalty or drop goal has been scored.

Players who are expected to perform goal kicks or place kicks must be able to demonstrate a long-lasting oscillation with hip extension and maximum knee flexion during the backswing, followed by hip flexion with knee extension. Specific joint requirements for the kicking leg include at least 100° of knee flexion and 10°-15° of hip extension during the backswing, followed by 50° of hip flexion and 60° of knee flexion at ball impact. The player must also be able to demonstrate a rigid foot with full ankle plantarflexion and toe flexion at ball contact. The forward swing demands at least 120° of hip flexion with 20° of knee flexion and the player must demonstrate adequate hamstring length and eccentric hamstring strength to avoid injury with high kicks. For the non-kicking leg, adequate single leg balance and proprioception are essential for safe performance of kicking requirements during game play. Control and accuracy must be stressed with all kicking drills, and the player must demonstrate adequate hamstring length and eccentric hamstring strength to avoid injury with high kicks.

Kicking drills should begin with short distances with a focus on control and kicking mechanics, and gradually progress to longer distances with greater velocity. Players should start by holding the ball
in their hands and performing drop kicks at short distances into netting in the clinic. Once they have mastered this skill without pain or difficulty, they can progress to goal or place kicks with a tee. Prior to performing the goal kick, ensure the athlete is able to perform the proper approach and dry kicks in the clinic without aggravation of symptoms. Once they have demonstrated proper mechanics without compensations, they can add the ball and progress from short to long distances.

Section testing elements for return to kicking include the ability to perform full intensity kicks (at least 5-10 kicks in a row) in the clinic without symptom provocation, as well as full game play without symptom provocation.

SCRUN PROGRESSION

The purpose of the scrum is to restart play quickly, safely, and fairly after a minor infringement or stoppage. It is composed of eight players, typically forwards, who bind together to form a cohesive pack, first with each other and then against an opposing pack to compete for possession of the ball as it is rolled by the scrum half between the resultant tunnel that separates the two teams (Figures 3a and 3b). Each scrum is composed of three units or rows: the front row (two props with a hooker between them), the second row (also referred to as locks), two flankers, and a number 8. Tight forwards include the two props, the hooker, and the two locks. Loose forwards include the two flankers and the number 8. In a sample of professional rugby players an average of 29 ± 6 scrums occurred per game with a mean duration of 5.8 ± 0.5 seconds per scrum.45

Relative to the incidence of other injuries that occur during the sport, scrum-related injuries are reportedly very small, typically cited at an average of less than 8% of all reported injuries sustained during game play.5,86-89 However, the scrum is correlated with the highest risk per event for injury, in addition to the most days lost per event when compared to all contact events that occur during rugby.90 Cata-
strophic injuries occurring during the scrum are not uncommon and have been reported to be as high as 40% of all reported catastrophic injuries.91-93 While the incidence of these injuries is low, they have the propensity to cause debilitating acute or chronic injury.92,94-97 Injury mechanisms of spinal injuries occurring from the scrum are typically classified as either hyperflexion or buckling,85 which may cause acute cervical root injuries during matches or the repeated cumulative stresses in the same manner may contribute to lumbar disc injuries.94

Multiple studies have investigated the biomechanics and force production of rugby scrummaging.98-102 Preatoni et al99 utilized an instrumented scrum machine to analyze the biomechanical demands of scrummaging. During the scrum, there is a characteristic force pattern that includes a short-duration peak at impact, a sharp decrease in force to its lowest level, followed by a steady escalation to an overall steady-state sustained force. Peak engagement forces ranged from 8700 to 16500 Newtons. When forces were normalized by total body weight amongst the scrum packs, there were no discrepancies in peak engagement force between genders or age level, except for international and elite players.

During the scrum, players must bind to a teammate using their entire upper extremity from shoulder to hand in order to grasp a teammate’s body at or below the level of the axilla, which typically requires at least 90 degrees of shoulder horizontal abduction.103 Due to their position between two props on either side, the hooker requires greater shoulder range of motion and greater end range shoulder strength to maintain this suspended position during the scrum. Isometric cervical strength is especially important for those in the front row due to the forces described previously for adequate stabilization of the cervical spine.

Amongst the props for each team there exists a loose head prop, who is only bound to the opponent's scrum by his inside shoulder, and a tight head prop, who is bound to the opponent's scrum between the opposing hooker and loose head prop. Requirements for the tight head prop will be greater than those for their loose head counterpart due to the more constricted and thus more vulnerable position. Players involved in the scrum must also be able to tolerate the physical demands of the crouched position. According to Quarrie et al103 the range of motion requirements for scrummaging include 123 degrees of hip flexion, 107 degrees of knee flexion, and 12 degrees of ankle dorsiflexion.

Scrummaging requires dedicated strength training in the weight room for both the upper and lower extremities in addition to core stability, such as those listed in Table 3 and shown in Figures 4a-4h. Emphasis should be placed on those exercises simulating the crouched position required for the scrum. In addition, promotion of triple extension should not be neglected, as lower extremity power production as a cohesively bound unit is essential for driving the scrum pack forward against a resisting opponent.
In addition, players attempting to return to scrumming should do so in a functional progression (Table 4). It is encouraged that the clinician gradually incorporate simulated opponents before finally advancing to a full scrum (Figures 5a, 5b, 5c). A player may return to scrummaging in a competitive environment when he or she demonstrates the ability to perform full intensity scrummaging in practice with all eight forwards.

TACKLING, RUCKING, MAULING PROGRESSION

Tackling

Tackling is an essential component of the sport of rugby, and emphasis on proper technique should begin as early as possible in a player’s career given that players are expected to develop and withstand tremendous forces without injuring themselves or others. A tackle is technically defined as an event that occurs on the field of play during which the ball carrier is held by one or more opponents, and either the ball or the hand of the arm carrying the ball makes contact with the ground. An average of 590 ± 50 completed tackles and an average of 67 ± 14 missed tackles per player occurred in a study investigating a professional New Zealand rugby team over two seasons.104 In a two-season prospective cohort of 645 professional rugby union players from 13 English Premiership rugby union clubs, the flanker completed the highest number of tackles per match amongst all positions, with an average of 13 ± 6.90 However, the frequency of being tackled was not significantly different between all positions.45 With regards to injury, previous reports amongst senior and elite rugby players revealed that the most prevalent cause of injury was the tackle (24-58%), followed by the ruck (6-17%), and then the maul (12-16%).5,6,89,105-109 In a prospective cohort of 645 professional rugby players followed over two seasons, the most common injuries sustained during collision events were thigh muscle hematomas, head/facial fractures, knee and foot/ankle ligament injuries dur-

<table>
<thead>
<tr>
<th>Table 3. Strength Drills for Scrummaging and Tackling: perform 3x/week with at least 1 rest day in between</th>
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<tbody>
<tr>
<td><strong>Upper Body Strength</strong></td>
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<tr>
<td>- Cervical isometric drills</td>
</tr>
<tr>
<td>- Flexion, extension, lateral side-bending (right/left), rotation (right/left)</td>
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<tr>
<td>- Begin with self-resisted exercise and transition to theraband resistance</td>
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<tr>
<td>- Incorporate therapist applied perturbations to enhance stability, activation, and speed of reaction</td>
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<tr>
<td>- Shoulder horizontal abduction/adduction</td>
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<tr>
<td>- Scapular fly/chest fly with cable or free weights</td>
</tr>
<tr>
<td>- Prone plank upper extremity sliders</td>
</tr>
<tr>
<td>- Can also incorporate diagonals</td>
</tr>
<tr>
<td>- Monitor for correct activation of scapular retractors during performance and decrease over-activation of upper trapezius</td>
</tr>
<tr>
<td>- Horizontal row</td>
</tr>
<tr>
<td>- Bent over with free weight or hanging from barbell</td>
</tr>
<tr>
<td>- Grip strengthening</td>
</tr>
<tr>
<td><strong>Core Stability</strong></td>
</tr>
<tr>
<td>- Core activation in horizontal/crouched position</td>
</tr>
<tr>
<td>- Begin with activation in hooklying then progress to sitting→standing→crouched</td>
</tr>
<tr>
<td>- Anti-flexion, anti-rotational stability</td>
</tr>
<tr>
<td>- Start from quadraped and progress to prone on unstable surfaces, such as prone over BOSU or ball</td>
</tr>
<tr>
<td>- Incorporate therapist applied perturbations to enhance stability, activation, and speed of reaction</td>
</tr>
<tr>
<td><strong>Lower Extremity Power</strong></td>
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<tr>
<td>- High-load back squats</td>
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<tr>
<td>- Ensure proper activation of core stabilizing musculature with maintenance of proper lordotic curve</td>
</tr>
<tr>
<td>- High load cleans (progressing to clean and jerks when appropriate)</td>
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<tr>
<td>- Vertical jump</td>
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<tr>
<td>- Incorporate band resistance if available</td>
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<tr>
<td>- Burpee box jumps</td>
</tr>
<tr>
<td>- Promotion of triple extension (hip, knee, ankle)</td>
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</tbody>
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Figure 4 (a-h). Strength drills for scrimmaging: a) Resisted prone cervical extension over bench, b) Chest fly with dumbbells, c) Reverse fly with dumbbells, d) Horizontal row with dumbbells, e) Half kneeling press with lateral cable, f) Quadruped upper extremity flexion with contralateral lower extremity extension over ball, g) Side plank with shoulder abduction, h) Posterolateral upper extremity slide.
The requirements for tackling are nearly identical to those for scrummaging. However, players are required to develop more power in a less controlled and more dynamic environment. Intuitively, those players who approach a contact situation with the greatest momentum typically produce the largest peak force during impact. Strength and conditioning drills to be performed prior to a player's return to tackling are outlined in Table 3.

As mentioned in the Scrum Progression section, grip strength is essential for the sport of rugby, as tacklers are required to pin their opponents to the ground before the phase is concluded. Therefore, suggested progressive grappling drills are essential to an athlete's successful return to competition. These drills may be performed by the clinician, a teammate, or a member of the coaching staff in an open area in the clinic or on the field. Beginning in a tall kneeling position the athlete should practice binding head on and then progressing to the side and from behind. Once this is completed, the athlete may begin to practice binding from a standing position utilizing the same intensity progression (Figure 6). For positional tolerance, the athlete should practice a stationary grapple to ensure proper positioning and absence of symptoms. Following this, the

<table>
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<th>Table 4. Field Progressions for Scrummaging</th>
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<tr>
<td>Field progressions for scrummaging performed with a partner, a) Binding for positional tolerance, b) Players performing squat in bound position, c) Rotations performed from bound position.</td>
</tr>
<tr>
<td>Without a Partner (begin with 5-10 second bouts and gradually increase to 30 second bouts)</td>
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<tr>
<td>- Low prowler pushes</td>
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<tr>
<td>- Sprints with increasing weight as tolerated</td>
</tr>
<tr>
<td>- Resisted sport cord runs (upright)</td>
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<tr>
<td>- Resisted sport cord bear crawl</td>
</tr>
<tr>
<td>With One Partner/Opponent (must be able to tolerate positions for 20-30 seconds at a time)</td>
</tr>
<tr>
<td>- Simple binding (interlocking position with another player) in a crouched position for positional tolerance</td>
</tr>
<tr>
<td>- Bind + synchronous squat</td>
</tr>
<tr>
<td>- Bind + 45° rotation in each direction</td>
</tr>
<tr>
<td>Sequential Scrum Transitions (perform progressions on separate days to ensure tolerance; begin with 5-10 minutes of practice time and allow progression if no pain reproduction)</td>
</tr>
<tr>
<td>- 3 on 3 (front row)</td>
</tr>
<tr>
<td>- 5 on 5 (front row + 2nd row)</td>
</tr>
<tr>
<td>- Full 8 member pack</td>
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The requirements for tackling are nearly identical to those for scrummaging. However, players are required to develop more power in a less controlled and more dynamic environment. Intuitively, those players who approach a contact situation with the greatest momentum typically produce the largest peak force during impact.104 Strength and conditioning drills to be performed prior to a player's return to tackling are outlined in Table 3.

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The athlete should begin to bind before walking forward and then backwards while maintaining this bound position. Once this has been accomplished, the athlete should perform clockwise and counterclockwise circles while bound to an opponent. To challenge the returning player's reaction ability, the opponent may then change directions with an attempt to shake the athlete off. In an effort to simulate the dynamic nature and duration of a tackle the athlete may then begin practicing an explosive initial contact with an opponent. This initial contact may then be followed by a resisted drive against an opponent with a final progression towards shaking off an opponent before the addition of a sprint.

Once this progression is successfully completed without symptom provocation, the athlete may advance to drills performed on the field. All field tackling drills should be executed in a gradually progressive fashion. It is the authors' recommendation to begin initially at 25% intensity prior to progressing to 50%, 75%, and finally 100% intensity as tolerated. It has been previously reported that fatigue can decrease an athlete's neuromuscular control, performance, and lower extremity mechanics. Additionally, Gabbett reported a decrease in rugby players' tackling ability in addition to other performance elements as exercise intensity increased, resulting in a progressively fatigued state. If available, it is recommended that a tackling dummy or shield be utilized preceding a live opponent. Forwards are typically involved in tackling from a shorter distance, whereas backs are commonly involved in more open-field tackling events at greater velocities. Therefore, in an effort to closely correlate position-specific demands, the distances should be varied accordingly. In addition, tackles should be performed at a variety of angles to mimic the assorted demands required during gameplay.

In an effort to mimic the reactive ability and on-field decision making required for tackling, three cones should be set up to create two running lanes for an opponent. An opponent is instructed to sprint towards the cones before finally choosing one of the two lanes to run through before being bound by the recovering athlete from a standing position. The athlete's position is then transitioned to prone facing the opponent before transitioning to prone facing away from the opponent. This sequence should then be progressed from binding to tackling utilizing the previously mentioned graduated advancement of intensity. Gabbett lists the following as technical criteria for proficient tackling in rugby, “accelerating into the contact zone; contacting the target in the center of gravity; contact the target with the opposite shoulder to leading leg; body position square/aligned; arms wrapping around the target on contact; leg drive on contact; watching the target onto the shoulder; and center of gravity forward of base of support.” Once the athlete is able to demonstrate proficient technique from a rested state, he or she should then be evaluated using a repeated-effort protocol in order to induce fatigue.

Rucking is a common event occurring immediately following a tackle in which a player is effectively pinned to the ground and the tackled player places the ball on the ground (Figures 7a and 7b). The site where the ball is placed demarcates the area of possession for the offensive team. Players from both teams form opposing forces in an attempt to either maintain or gain possession utilizing various strategies and techniques, typically involving a charge leading with the shoulder. Amongst 13 professional teams, an average of 142.5 rucks occurred per match. Although any player may participate in a ruck, the forwards are typically involved more frequently than the backs.

A maul is formed if the ball carrier is unable to be successfully pinned to the ground and at least one opponent and one bound teammate hold the ball carrier upright. The play must continue to move towards a goal line and may not remain stationary for more than five seconds. An average of 18.4 mauls have been reported to occur in an individual profes-
The requirements for rucking and mauling are nearly identical to those required for scrummaging. However, rucks require more power development in a less controlled and more dynamic environment than scrummaging. In addition, mauling requires power development while the athlete maintains a more upright position. Forwards participate in an average of 3.2 times more rucks and mauls combined than backs.45

A useful drill for the recovering player is to simulate a player using a tackle bag by laying the bag on the ground to simulate a ruck or upright to simulate a maul. The player then charges towards the bag in an attempt to "clear" the ruck or advance the maul. Tackling shields may be used to simulate opposing players initially before progressing to live opponents. As the player is able to demonstrate competence with these drills, the intensity and angle of the charge may be manipulated further. Return to full gameplay should be done so in conjunction with successful completion of the other aspects of gameplay in which he or she is involved as discussed in the previous sections of this commentary.

CONCLUSION
As evidenced by the detailed proposed guidelines, the sport of rugby places very specific and unique demands on the body when returning a rugby player to full participation. Rehabilitation may be tailored to the position played, the level of the athlete, and the type and involvement of the injury. The intention of this proposed program is to provide a general outline for rehabilitation specialists to utilize for rugby players during rehabilitation that takes into account the unique aspects of functional performance and return to sport phases in order to prepare an athlete for return to full gameplay. It also provides educational components on general gameplay, testing components, suggested specific movement progressions, and sport- and position-specific progressions. Prior to initiation of this return to sport program, all athletes should demonstrate achievement of the baseline requirements in order to decrease risk of re-injury and to ensure safe and efficient return to sport.

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