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ABSTRACT

**Background:** Rehabilitative ultrasound Imaging (RUSI) is increasingly used in the management of musculoskeletal conditions as it provides an objective measure of muscle function while being less invasive than needle electromyography. While research has documented the ability to reliably measure trunk muscles in patients with back pain, no study to date has used RUSI to quantify infraspinatus muscle function in patients with shoulder impingement syndrome (SIS).

**Hypothesis/Purpose:** The purpose of this study was to examine the intra-rater and inter-rater reliability of measuring infraspinatus muscle thickness with RUSI and to compare such measures during resting versus contracted muscle states and in the symptomatic versus asymptomatic shoulders in patients with SIS.

**Study Design:** Cross-sectional, measurement study

**Methods:** Fifty-two participants with unilateral SIS underwent a standard baseline examination to include RUSI of the infraspinatus muscle bilaterally. Images were acquired at rest and during a submaximal isometric contraction, by two novice examiners. The isometric contraction was elicited by having prone participants externally rotate their shoulder from a position of 90° abduction into a dynamometer and hold a static force of 20 mmHg (approximately 20-30% maximal voluntary contraction). Images were captured using a standardized placement of the transducer placed just inferior to the spine of the scapula along the medial scapular border and measured off-line using Image J software (V1.38t, National Institutes of Health, Bethesda, Maryland).

**Results:** Estimates (ICCs) for thickness measurements ranged between 0.96 and 0.98 for intra-rater reliability and between 0.87 and 0.92 for inter-rater reliability. Reliability was substantially lower (ICC = 0.43 to 0.79) for calculations of percent thickness change. The infraspinatus muscle was significantly thicker when contracted (19.1mm) than during rest (16.2mm) in both shoulders (p < 0.001). There was also a statistically significant interaction between contraction state and shoulder (p = 0.026), indicating that the change in thickness that occurred during contraction was significantly smaller in the symptomatic shoulder than in the asymptomatic shoulder.

**Conclusion:** RUSI measurements of infraspinatus muscle thickness appear to be highly reliable, both within the same examiner and between different examiners, in patients with SIS. Moreover, such measurements were different in rested and contracted states of the infraspinatus, as well as, between the symptomatic and asymptomatic shoulders of patients with unilateral SIS.

**Level of evidence:** Level 2

**Key words:** Infraspinatus muscle, muscle function, reliability, shoulder impingement syndrome, shoulder pain, ultrasound imaging
INTRODUCTION
Shoulder disorders are second only to low back pain as the most common musculoskeletal disorder, with shoulder impingement syndrome (SIS) being the most prevalent.1,2 SIS is described as pain or pathology located in the rotator cuff tendons, subacromial bursa and subacromial space.2 There are many factors that are believed to be involved with the pathogenesis of SIS; repetitive use of the shoulder muscles, incorrect scapulothoracic rhythm, instability of the glenohumeral joint, degeneration of the rotator cuff tendons, and altered shapes of the acromion.3,4 Patients with SIS have been found to have decreased strength during resisted external rotation of the shoulder5 and a significantly elevated position of the humeral head during arm elevation when compared to individuals without shoulder pain.6,7 Alterations in the relative contribution of the deltoid and rotator cuff muscles during shoulder activities have also been reported in patients with SIS potentially leading to unwanted humeral head superior translation.8,9 It is hypothesized that the decreased function of the infraspinatus, as seen in SIS, contributes to the production of SIS pain.3,4

Although the construct of muscle function is multifactorial, the function of the infraspinatus has been measured through manual muscle testing (isometric force), electromyography (electrical activity), isokinetic testing (isokinetic force), and magnetic resonance imaging (volume changes) studies.5,8–10 These methods can be costly, time consuming, non-specific, and invasive or uncomfortable procedures. An evolving, non-invasive method of quantifying muscle function is rehabilitative ultrasound imaging (RUSI).11,12 Used to date primarily in the muscles of the trunk, RUSI relies on measurements taken of muscle morphology (thickness or cross sectional area) at rest and comparing them to morphology measurements during isometric muscle contraction. The amount of change in morphology (thickness or cross sectional area) during the contraction or task is considered an indirect measure of muscle function.11 Studies have consistently found RUSI to provide reliable measures of abdominal and lumbar multifidus muscle thickness.13 Similar studies of trunk muscles have also found RUSI to be helpful in discriminating between patients with back pain and those without back pain.14–16 However, when comparing RUSI measures to the criterion standard of kinesiological EMG, studies have found mixed results that seem to depend both upon the muscle being studies and the contraction strategy used.17

Most studies to date have focused on muscles of the trunk in patients with back pain, however recent studies have examined the use of RUSI in scapular and shoulder muscles.18–22 Specifically, the reliability of RUSI measures of trapezius muscle morphometry and function have been described.21–24 Two studies have measured muscle function of shoulder muscles using RUSI, however, they were either performed in asymptomatic individuals or the results were not quantified numerically.19,20 Therefore, the purpose of this study was to estimate the intra-rater and inter-rater reliability of RUSI measurements of infraspinatus muscle thickness in patients with unilateral SIS. Additionally, RUSI measurements of infraspinatus muscle thickness during resting versus contracted muscle states were compared and in the symptomatic versus asymptomatic shoulders.

Methods
Participants
Fifty-two volunteers between the ages of 18-60 with current unilateral shoulder pain were recruited through email, flyers, and service announcements that were posted around or electronically distributed to military installations around San Antonio, Texas. Participants were included if they had shoulder impingement syndrome, as defined by; anterior and/or lateral shoulder pain that reached at least 4/10 on the Numerical Pain Rating Scale (NPRS) with daily activity and were positive for at least two of the three following clinical diagnostic criteria for SIS5: positive Hawkins-Kennedy impingement sign, pain in the painful arc between 60-120°, and/or pain or weakness with the infraspinatus manual muscle test. Participants were excluded if they had shoulder impingement syndrome, as defined by: anterior and/or lateral shoulder pain that reached at least 4/10 on the Numerical Pain Rating Scale (NPRS) with daily activity and were positive for at least two of the three following clinical diagnostic criteria for SIS5: positive Hawkins-Kennedy impingement sign, painful arc between 60-120°, and/or pain or weakness with the infraspinatus manual muscle test. Participants were excluded if they had a history of prior trauma or shoulder surgery, signs of cervical radiculopathy, radiculitis or referral from the cervical spine, evidence of full-thickness rotator cuff tear, signs of adhesive capsulitis, known pregnancy, or any previous injection, acupuncture, dry needling or strengthening interventions within the past six months. Participants were also included in an interventional dry needling study, therefore, anyone with
potential contraindications to dry needling (known pregnancy, anticoagulation medications and blood clotting disorders) were also excluded.

Examiners
All RUSI measures were performed by physical therapy doctoral students with no previous experience in RUSI. Prior to testing, examiners underwent approximately 12 hours of hands-on training with faculty co-investigators experienced with RUSI. Additionally, examiners performed pilot assessments on 10 asymptomatic participants for practice and methodology refinement. Ultrasound examiners were blinded to the subject’s affected shoulder side and to all prior measurements during imaging.

Procedures
The RUSI device used in this study was the SonoSite Titan and M-Turbo with a 38mm linear array transducer. Imaging began with the left shoulder for all participants regardless of which side was symptomatic. Subjects were prone with their left shoulder abducted to 90 degrees. Subjects’ shoulders and upper arm were supported by the table while the crease of the subject’s elbow rested comfortably on the edge of the table and allowed the forearm to passively hang vertically. Their wrist was secured to a pressure cuff, which was also secured to the table to prevent unintended movement and enable a measureable, standardized isometric contraction of the infraspinatus muscle. The subject's head was turned ipsilaterally so they could see the pressure cuff gauge measuring the mmHg exerted against the cuff (Figure 1).

During imaging, the examiner first identified the medial border of the scapula while scanning in the transverse plane parallel with the orientation of the infraspinatus muscle fibers. The ultrasound transducer was then positioned so the superomedial border of the spine of the scapula was lined up on the left side of the ultrasound screen. Examiners exerted as little pressure through the ultrasound head as possible to avoid compressing the infraspinatus muscle and inadvertently changing its shape and/or thickness. After an image of the subject’s infraspinatus was taken at rest, they were then instructed to externally rotate their shoulder until a pressure of 20 mmHg (approximately 20-30% maximal voluntary contraction) was exerted through the cuff secured to their wrist. The subject maintained that pressure, using visual feedback from the gauge, until an ultrasound image of their isometrically contracted infraspinatus was taken. A submaximal contraction was desired for the study and 20 mmHg was chosen to standardize the subjects’ contractile force. This pressure was chosen in an attempt to reduce variability between subjects and was low enough that subjects could maintain the contraction without increasing their pain or causing fatigue while still showing a change in muscle thickness. As soon as the image was taken the subject was allowed to relax and the transducer was removed.

These methods were repeated two more times on the left shoulder for a total of six images; three at rest and three contracted. Although the exact time between images was not standardized, the protocol resulted in approximately one minute between each image acquisition. Once the primary examiner collected all six images, the second examiner then repeated the process again on the left shoulder and collected six more images. After twelve images total had been captured, the process was repeated on the subject’s right shoulder with the examiners resuming their original roles and once more each taking a set of six images. These 24 images completed the image collection process.

Measurements
After data collection, the images were downloaded to a laptop computer and measured using Image J software (V1.38t, National Institutes of Health, Bethesda, Maryland). The thickness of the infraspinatus muscle was measured in the center of the

Figure 1. Imaging and isometric infraspinatus muscle contraction procedure
image and reported in millimeters (to the nearest hundredth). This measurement was taken from the inferior-most aspect of the superficial fascia to the most superior aspect of the infraspinous fossa; which appeared as a bright, continuous hyperechoic line spanning the width of the screen (Figure 2). This process was repeated on every image. After all the measurements were taken, the depth of the infraspinatus at rest was subtracted from the depth during contraction to find the difference.

**Statistical Analysis**

All data were analyzed with SPSS Version 21 software (Chicago, IL). The dependent measures were resting thickness, contracted thickness, and percent thickness change of the infraspinatus muscle. Percent thickness change was calculated by the equation \(\text{Thickness}_{\text{contracted}} - \text{Thickness}_{\text{rest}} / \text{Thickness}_{\text{rest}}\).

Intraclass correlation coefficients (ICCs) with 95% CIs were calculated to assess intra-rater (ICC\(_{3,3}\)) and inter-rater (ICC\(_{2,1}\)) reliability. Based on previous work investigating RUSI of reliability of abdominal muscles, the mean of three measures was used as the analysis of interest for intra-rater reliability.\(^25\) To quantify measurement error, standard error of measurement (SEM) was calculated as \(\text{SD} \times \sqrt{1-\text{ICC}}\). Minimal detectable change (MDC) was calculated as \(1.96 \times \text{SEM} \times \sqrt{2}\) and represents the minimal change in thickness that must occur to be 95% confident that a true change occurred.\(^26,27\) Both SEM and MDC were calculated using the ICC estimates for intra-rater reliability.

Differences in RUSI measurements were assessed using 2x2 repeated measures analysis of variance (ANOVA) on muscle thickness for contraction state (resting vs. contracted) and shoulder (symptomatic vs. asymptomatic) using alpha = 0.05. A main effect for contraction state was examined to determine if RUSI was able to distinguish between resting and contracted states. The interaction between contraction state and shoulder was examined to determine if RUSI was able to discriminate the amount of thickness change between symptomatic and asymptomatic shoulders.

**Results**

Demographic and patient history information for the 52 participants is listed in Table 1. Participants’ symptoms were generally chronic in nature and caused moderate shoulder-related disability. Mean infraspinatus muscle thickness values and percent thickness change from rest to contracted state are listed in Table 2. Point estimates (ICCs) for thickness measurements ranged between 0.89 and 0.92 for intra-rater reliability and between 0.96 and 0.98 for inter-rater reliability. Reliability was substantially lower (ICC = 0.43 to 0.79) for calculations of percent thickness change (Table 2). Estimates of measurement error were very small for thickness measures (0.6mm to 0.8mm), but substantially larger for percent thickness change (5.7 to 5.8%).

There was a statistically significant main effect for contraction state (\(p < 0.001\)) indicating that the infraspinatus muscle was significantly thicker when
The study is the first to use RUSI to quantify infraspinatus muscle function in patients with SIS. Measurements of infraspinatus muscle thickness were found to be highly reliable, both within the same examiner and between different examiners. Additionally, RUSI measurements of infraspinatus muscle thickness were different in resting and contracted conditions and between the symptomatic and asymptomatic shoulders of individuals with unilateral SIS.

The reliability estimates in the current study were very similar to those found using RUSI to measure abdominal and lumbar muscle thickness across multiple studies (ICC greater than 0.90) for both intra-rater and inter-rater reliability. Reliability estimates were also similar to the studies that have investigated RUSI measures of thickness of the trapezius muscle. As expected, intra-rater reliability was generally higher than inter-rater reliability, especially when such estimates were based on a mean of three measurements. Additionally, the reliability estimates of percent thickness change calculations were substantially lower than those derived from thickness measures. As previously hypothesized, the reason for this decrement of reliability likely has to do with the compounding of measurement error when performing calculations based on both resting and contracted thicknesses.

Table 1. Baseline Demographic and History Information

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Mean +/- SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, (years)</td>
<td>43.6 ± 10.2</td>
</tr>
<tr>
<td>Sex (% women/%men)</td>
<td>37%/63%</td>
</tr>
<tr>
<td>BMI, (kg/m²)</td>
<td>28.4 ± 4.3</td>
</tr>
<tr>
<td>Pain in dominant shoulder</td>
<td>64%</td>
</tr>
<tr>
<td>Duration of symptoms, m*</td>
<td>11.2 (5.1, 38.3)</td>
</tr>
<tr>
<td>PSS, total†</td>
<td>64.3 ± 10.3</td>
</tr>
<tr>
<td>Pain subscale</td>
<td>16.7 ± 4.5</td>
</tr>
<tr>
<td>Satisfaction subscale</td>
<td>4.1 ± 2.4</td>
</tr>
<tr>
<td>Function subscale</td>
<td>43.4 ± 6.6</td>
</tr>
</tbody>
</table>

Abbreviations: BMI, body mass index; PSS, Pennsylvania Shoulder Score
†Median, Interquartile range

Table 2. Reliability of Infraspinatus RUSI measures

<table>
<thead>
<tr>
<th></th>
<th>Inter-rater</th>
<th>Intra-rater</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean +/- SD</td>
<td>ICC (95% CI)</td>
</tr>
<tr>
<td>Symptomatic Shoulder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relaxed Thickness</td>
<td>16.4 +/- 4.1 mm</td>
<td>.89 (.82-.94)</td>
</tr>
<tr>
<td>Contracted Thickness</td>
<td>19.0 +/- 4.3 mm</td>
<td>.92 (.87-.96)</td>
</tr>
<tr>
<td>% Thickness Change</td>
<td>17.1% +/- 10.6%</td>
<td>.43 (.19-.62)</td>
</tr>
<tr>
<td>Asymptomatic Shoulder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relaxed Thickness</td>
<td>16.0 +/- 3.6 mm</td>
<td>.87 (.78-.92)</td>
</tr>
<tr>
<td>Contracted Thickness</td>
<td>19.1 +/- 4.0 mm</td>
<td>.90 (.83-.94)</td>
</tr>
<tr>
<td>% Thickness Change</td>
<td>19.9% +/- 10.3%</td>
<td>.61 (.41-.75)</td>
</tr>
</tbody>
</table>

Figure 3. Change in infraspinatus muscle thickness between rest and contraction by shoulder

contracted (19.1mm) than during rest (16.2mm) across both shoulders. There was also a statistically significant interaction between contraction state and shoulder (p = 0.026), indicating that the change in thickness that occurred during the submaximal contraction was significantly smaller in the symptomatic shoulder than in the asymptomatic of patients with SIS (Figure 3).

Discussion

RUSI is an evolving tool used to non-invasively quantify muscle function. Studies using RUSI to date have primarily focused on muscles of the trunk in relation to patients with back pain. Rotator cuff muscles, particularly the infraspinatus, have been found to have deficits in patients with SIS, however, quantifying such deficits has been challenging, as it has predominantly involved either imprecise subjective methods (manual muscle testing) or technically complex procedures (electromyography). The current study is the first to use RUSI to quantify infraspinatus muscle function in patients with SIS. Measurements of infraspinatus muscle thickness were found to be highly reliable, both within the same examiner and between different examiners. Additionally, RUSI measurements of infraspinatus muscle thickness were different in resting and contracted conditions and between the symptomatic and asymptomatic shoulders of individuals with unilateral SIS.

The reliability estimates in the current study were very similar to those found using RUSI to measure abdominal and lumbar muscle thickness across multiple studies (ICC greater than 0.90) for both intra-rater and inter-rater reliability. Reliability estimates were also similar to the studies that have investigated RUSI measures of thickness of the trapezius muscle. As expected, intra-rater reliability was generally higher than inter-rater reliability, especially when such estimates were based on a mean of three measurements. Additionally, the reliability estimates of percent thickness change calculations were substantially lower than those derived from thickness measures. As previously hypothesized, the reason for this decrement of reliability likely has to do with the compounding of measurement error when performing calculations based on both resting and contracted thicknesses.
The finding that RUSI measurements of infraspinatus muscle thickness were able to distinguish between resting and contracted conditions and between the symptomatic and asymptomatic shoulders helps establish a low level of initial validity of such measurements. Discriminative validity (also called extreme groups or known groups method) is considered a form of construct validity that is supported when measures can discriminate between individuals or conditions that are thought to be different on a relevant construct. Construct validity of RUSI measures of trunk muscle function has been supported by differences based on pain-related conditions (e.g. different in patients with back pain vs. asymptomatics), posture or activity (e.g. different between slouched sitting and erect standing), and anthropometric conditions (e.g. different in men vs. women). Criterion validity of RUSI measures has been supported in other muscles by studies comparing them to criterion standard measures such as EMG or MRI. Two previous studies have preliminarily investigated the RUSI of the infraspinatus muscle. Jull-Kristensen et al compared resting infraspinatus muscle thickness as measured by RUSI and MRI and found an 8% mean difference between the measures in asymptomatic individuals. Of note, the mean infraspinatus muscle thickness was very similar to the resting thickness found in the current study (18 mm vs. 16 mm). Boehm et al imaged the infraspinatus muscle during contraction in patients with varying shoulder pathologies. Although they didn't quantify muscle thickness, they subjectively assessed the contraction patterns and reported good agreement between different raters' assessments. The only other study to compare the muscle thickness measures between shoulder of patients with unilateral shoulder pain did so of the lower, middle, and upper trapezius. Unlike the current study, they did not find any differences between the symptomatic and asymptomatic shoulders nor between people with and without shoulder pain.

Limitations
Although the current study found clear differences in infraspinatus muscle thickness between resting and contracted conditions, the differences between asymptomatic and symptomatic shoulders were very small and within estimates of measurement error. Therefore, while one can conclude that such differences are not solely due to sampling error, they may be attributable to measurement error. Moreover, since only one other study to date has quantified infraspinatus muscle thickness using RUSI, there is currently no data to determine what degree of “thickening” constitutes clinically relevant change. Additionally, this study did not document whether participants experienced pain with active infraspinatus contraction during the measurements. Pain during muscle contraction may have caused compensatory muscle action (e.g. more teres minor contraction) in order to perform the described task, which may have affected results. However, the methods were designed to minimize variance in volitional muscular contractions with the standardized contraction pressure measured by the pressure cuff. Each participant was able to externally rotate their shoulder to meet the standardized pressure.

Future research should compare measures of infraspinatus muscle activation measured by EMG with changes in thickness measured by RUSI. Future research should also assess the clinical responsiveness of RUSI measures of infraspinatus muscle thickness longitudinally during a course of rehabilitation aimed at improving muscle function.

Conclusion
RUSI measurements of infraspinatus muscle thickness appear to be highly reliable, both within the same examiner and between different examiners, in patients with SIS. Furthermore, in the current study, RUSI measurements of infraspinatus muscle thickness were different in resting and contracted conditions and between the symptomatic and asymptomatic shoulders. Although the differences in infraspinatus muscle thickness between resting and contracted conditions were fairly large, the differences between asymptomatic and symptomatic shoulders were very small and within estimates of measurement error. If validated in future research, RUSI may allow for more objective quantifications of muscle impairments and be a useful adjunct to the physical examination in patients with SIS.

REFERENCES
1. Feleus A, Bierma-Zeinstra S, Miedema H, Bernsen R, Verhaar J, Koes B. Incidence of non-traumatic...


ABSTRACT

**Purpose:** Three-dimensional motion analysis is the “gold standard” for evaluating kinematic variables during treadmill running. However, its use is limited by temporal and financial restraints. Therefore, the purpose of this study was to assess the concurrent validity and reliability of 2D video analysis for frontal plane kinematic variables during treadmill running.

**Methods:** Twenty-four healthy male and female collegiate cross-country runners completed a running protocol at a self-selected speed. Frontal plane kinematic data were collected using 3D and 2D motion analysis systems. Variables of interest included contralateral pelvic drop (CPD), peak hip adduction angle (HADD), and peak knee abduction angle (KABD). Pearson Product Correlation Coefficients were used to determine the relationship between the 3D and 2D systems for each variable. Intra-Class Correlation Coefficients (ICC) were used to assess intra-rater reliability of the user of the 2D software.

**Results:** The 2D testing method demonstrated excellent intra-rater reliability for peak HADD (ICCs: 0.951-0.963), peak CPD (0.958-0.966), and peak KABD (ICCs: 0.955-0.976). Moderate correlations between 2D and 3D measures of HADD on the left (0.539; p=0.007) and the right (0.623; p=0.001) and peak KABD on the left (0.541; p=0.006) lower extremity were found. No statistically significant correlation of CPD was found between the 2D and 3D systems. The 2D measure of CPD had a strong correlation to the 2D assessment of HADD on both the left (0.801; p=0.0001) and the right (0.746; p=0.0001) extremity.

**Conclusion:** These findings and the ease of data capture using 2D software provide support for the utility of 2D video analysis in the evaluation of frontal plane variables, specifically HADD.

**Level of evidence:** 2B

**Key words:** 2D video analysis, contralateral pelvic drop, hip adduction, running
INTRODUCTION
The incidence of lower extremity running injuries ranges from 19.4-79.3%. The predominant location for injury is the knee, comprising 42.1% of all running-related injuries. Patellofemoral Pain Syndrome (PFPS) is the most common running-related injury, followed closely by Iliotibial Band Syndrome (ITBS), plantar fasciitis, meniscal knee injury, and medial tibial stress syndrome. Current evidence suggests links between altered lower extremity biomechanics and running-related injuries. As both competitive and recreational running continues to grow in popularity, there is an ever-increasing need to examine individual running technique and running biomechanics with the goal of better informing injury prediction, prevention, and rehabilitation.

Standardized analyses of running gait offers an objective measure of multi-planar biomechanical risk factors that may contribute to injury in runners. Three frontal plane kinematic variables that are frequently analyzed clinically include contralateral pelvic drop, peak hip adduction angle, and peak knee abduction angle. All three variables have been extensively reported in the literature and have significant clinical implications with regards to injury rehabilitation and prevention in runners with a variety of diagnoses including PFPS, ITBS, and medial tibial stress syndrome. It has been theorized that contralateral pelvic drop, hip adduction, and knee abduction play roles in abnormal lower extremity biomechanics affecting the entire lower extremity kinetic chain. Specific biomechanical flaws, such as excessive or mistimed contralateral pelvic drop and knee abduction, along with femoral internal rotation, tibial external rotation, and foot pronation, have been theoretically linked to injury in a population of patients with PFPS. Kinematically, excessive hip adduction and hip internal rotation in weight bearing causes the knee joint to move medially relative to the foot, which results in tibial abduction and increased foot pronation. The end result is increased knee abduction, also known as dynamic genu valgus.

The gold standard for running gait analysis for both clinical and research purposes is three-dimensional (3D) motion-capture. However, the use of 3D analysis imposes significant financial, spatial, and temporal costs. These concerns suggest the need for clinically applicable alternatives. The most commonly used clinical alternative to 3D analysis is two-dimensional (2D) techniques. Two-dimensional systems often involve the use of standard video cameras and software to conduct kinematic analyses. Although 2D video analysis offers a more feasible option for evaluating kinematics during dynamic movements, this method is not without limitations. One proposed limitation includes how fully 2D motion analysis can capture dynamic and complex multiple planar motions. Specifically, dynamic knee valgus, which is a composite measure of hip adduction, femoral internal rotation, and tibial external rotation, may not be best represented by a simplified 2D assessment in the frontal plane.

As a result of these concerns, there have been multiple studies evaluating the validity and reliability of 2D software during functional movements. In regard to reliability, good within-day reliability (ICCs = 0.59-0.88) and good to excellent between-day reliability (ICCs = 0.72-0.91) on frontal plane projection angle (FPPA) measurements were found during single-leg squat and drop jump with single-leg landings. FPPA has been examined as a way to analyze dynamic valgus and predict or screen for injuries of the lower extremity, specifically at the knee. Excellent intra-rater reliability for 2D video analysis of hip adduction and knee valgus during single limb step downs20 and moderate to high intra-rater reliability for knee valgus during performance tests has been reported in the literature. In addition, Norris and Olsen found excellent inter-rater and intra-rater reliability for sagittal plane knee and hip flexion during mechanical lifting.

The results regarding concurrent validity of 2D motion analysis are mixed. Moderate correlation exists between 2D and 3D motion systems in the frontal plane for side stepping and side jump motions. However, 2D frontal plane kinematics of the knee during single-leg step down movements has been poorly correlated to 3D methods in the literature. 2D analysis of knee and hip kinematics in the sagittal plane during mechanical lifting was reported to be valid (r ≥0.95, p = 0.01). In contrast to these results, the utility of the frontal plane projection angle (FPPA) during single-limb squats and
single leg step downs was found to have little link to any specific changes in 3D joint kinematics.\textsuperscript{22,23} In the work of Willson and Davis, the FPPA measured by 2D methods reflected only 23-30\% of variance of 3D values.\textsuperscript{23}

Despite evidence regarding the reliability and validity of 2D video analysis for functional tasks, research on the use of this type of analysis during running is limited. McClay and Manal conducted one of the initial studies comparing 3D and 2D analyses in running gait analysis using 18 middle-aged recreational runners.\textsuperscript{19} While examining rearfoot variables, the researchers found that although the difference between peak 3D and 2D eversion angular displacement and eversion angular velocity was negligible, there were significant differences in eversion at toe-off and time to peak eversion, especially when the foot was abducted greater than 10 degrees.\textsuperscript{19} However, to the authors' knowledge, no studies have evaluated the concurrent validity and reliability of 2D video analysis at the hip and knee during treadmill running. Therefore, the purposes of this study were to assess the concurrent validity of 2D video analysis of the frontal plane kinematic variables of contralateral pelvic drop, peak hip adduction angle and peak knee abduction angle bilaterally during treadmill running, as well as to assess the intra-rater reliability of 2D video analysis. The first tested hypothesis was there would be a moderate correlation in all three kinematic variables between 2D and 3D software, indicating the concurrent validity of the 2D software. The second hypothesis was there would be excellent intra-rater reliability in the utilization of the 2D software. If found valid and reliable, there may be great potential for utilization of the 2D gait analysis software in the examination of running kinematics in the frontal plane. Furthermore, this finding would directly benefit current and future clinicians that perform screening and retraining for potentially faulty biomechanical patterns with affordable and feasible software.

**METHODS**

**Participants and Setting**

Twenty-four collegiate cross-country runners (male $n = 14$, age $20.2 \pm 1.2$ years; female $n = 10$, age $19.5 \pm 1.5$ years) had their running kinematics assessed. (Table 1) Informed written consent was obtained from each subject in accordance with the protocol approved by the Cincinnati Children’s Institutional Review Board and the rights of the subjects were protected throughout the study. Data collection took place immediately before the fall cross-country season in a laboratory setting. Subjects were excluded if they were currently under medical supervision and not fully cleared to participate in a structured running program. Inclusion criteria consisted of current participation on a collegiate cross-country team and self-reported free from pain during testing. Weekly mileage was greater than 30 miles for all subjects with an average of $64 \pm 18$ miles/wk.

**Treadmill Running Protocol**

Frontal plane thorax, pelvis, thigh, and shank motion were captured during a self-selected speed (SS) on a custom built treadmill (2.12 m length by 0.91 m width running surface). The criteria for determining SS was initially determined by asking each subject what pace he/she would select for an easy 20-min run, as done in Ford et al.\textsuperscript{26} The treadmill speed was blinded from the subject and adjusted, if requested by the subject, after a brief period of less than two minutes.

| Table 1. Characteristics of subjects included in the investigation |
|----------------------|-----------------|------------------|------------------|-----------------|
|                      | All (±SD) $n=24$ | Males (±SD) $n=14$ | Females (±SD) $n=10$ | p-value |
| Age (years)          | 19.9 (1.3)       | 20.2 (1.2)       | 19.5 (1.5)       | 0.22          |
| Weekly Mileage (miles)| 64.4 (17.9)     | 76.6 (11.7)     | 47.2 (8.0)       | <0.001        |
| Height (cm)          | 167.8 (23.1)     | 177.8 (6.7)     | 153.9 (30.5)     | 0.009         |
| Mass (kg)            | 59.7 (6.6)       | 64.0 (4.2)      | 53.7 (4.3)       | <0.001        |
| BMI                  | 20.0 (1.4)       | 20.1 (1.0)      | 19.9 (1.8)       | 0.724         |

BMI= Body mass index
Following the speed selection, the total acclimation period for each subject was approximately three to five minutes. Although Lavcanska and colleagues found that six minutes were required for gait to normalize for consistency of measurements, their subjects were inexperienced with treadmill running.27 Riley et al utilized an acclimation period of three to five minutes and found that mechanics on the treadmill could be generalized to overground running.28 The subjects in the current study were collegiate runners and all had previous experience in treadmill running. A one-minute trial was collected at each speed, simultaneously using both the 3D and 2D methods.

**3D Motion Analysis of Frontal Plane Variables**

Reflective markers were placed on the spinous process of the seventh cervical vertebra, sternal notch, sacrum, and bilaterally on the acromio-clavicular joint, upper arm, lateral epicondyle of the elbow, mid-wrist, anterior superior iliac spine (ASIS), greater trochanter, middle of distal femur just proximal to the superior pole of the patella, medial and lateral femoral condyles, tibial tuberosity, lateral knee joint line, middle of the distal tibia, and medial and lateral malleoli.29 (Figure 1) These markers were utilized to calculate three-dimensional angular displacement of the pelvis, thigh and shank during treadmill running. Three-dimensional marker trajectories were collected with Cortex software (Motion Analysis Corporation, Santa Rosa, CA) using a motion analysis capture system with 10 digital cameras (Eagle cameras; Motion Analysis Corporation), collected at 240 Hz. Twenty consecutive steps were analyzed for each subject. Three-dimensional kinematic variables were determined using Visual3D software (C-Motion, Inc., Germantown, MD). Specifically, knee and hip angular displacements were calculated as the motion of the distal segment relative to proximal segment. Pelvic motion was calculated as the motion of the segment relative to the global laboratory coordinates. Maximum and minimum kinematic data for pelvic, hip, and knee motions in the frontal plane were identified during the stance phase (treadmill contact to toe-off) for each consecutive step and then averaged.26,30

**2D Motion Analysis of Frontal Plane Variables**

During self-selected running trials, 2D kinematics in the frontal plane were assessed using Dartfish Motion Analysis Software (Dartfish, Fribourg, Switzerland). Video capture for 2D analysis was conducted concurrently during the 3D Motion Analysis data collection. The three variables of interest included peak contralateral pelvic drop angle (CPD), peak hip adduction angle (HADD), and peak knee abduction angle (KABD). Five trials of 2D analysis and 30 trials of 3D analysis were taken for both

![Figure 1. Marker Set for 3D Running Kinematic Assessment (used with permission of the International Journal of Sports Physical Therapy)]
the left and right lower extremities of each subject during midstance, where peak HADD, CPD, and KABD have been reported to take place in the literature.\textsuperscript{5,11,13,31} Pilot data from the lab demonstrated that the means of five trials under 2D analysis correlated well with the means taken from 30 trials for five different subjects, further validating the five trial method used for the 2D data. In addition, Lee and Farley found that the stance limb reached maximum compression at approximately the same time as the center of mass (COM) reached its lowest position near midstance.\textsuperscript{32} Since the peak 3D values and minimum COM values also occurred approximately at the same time in the current study, the minimum COM was determined as the point in the running cycle when the stance leg reached maximal compression or knee flexion. During each trial, the three variables were measured and calculated. (Figure 2) CPD was calculated as the angle subtended by one line connecting the ASIS with the stance and swing limb and a second line drawn perpendicular to the stance limb ASIS. The measurement was then subtracted from 90 degrees. The HADD was defined as the angle subtended by one line connecting the anterior superior iliac spines (ASISs) bilaterally and a second line connecting the ASIS of the test limb with the midpoint of the tibiofemoral joint. Finally, KABD was calculated as the angle subtended by a line connecting the ASIS of the stance limb with the midpoint of the tibiofemoral joint and a second line connecting the midpoint of the tibiofemoral joint and the bisection of the medial and lateral malleoli, similar to methods employed by Hollman and colleagues.\textsuperscript{20} The KABD evaluated in this study is also similar to the measurements of frontal plane projection angle (FPFA) that have been used widely in the literature.\textsuperscript{22,23}

Statistical Analysis

Concurrent validity of 2D motion was examined by comparing frontal plane angles derived from 2D kinematic analysis to measurements obtained using a 3D motion analysis system. Pearson Product Correlation Coefficients were used to determine the relationship between the 2D and 3D measurements of frontal plane kinematic variables of interest; specifically CPD, peak HADD, and peak KABD. These statistical analyses were used to assess the concurrent validity of the 2D measures obtained with the Dartfish Software. Second, the intra-rater reliability of the 2D assessment was examined. The intra-rater reliability of the 2D software was performed using Intra-Class Correlation Coefficients (ICC). Intra-rater reliability was evaluated by having the evaluator perform a test-retest analysis of the same frames one week apart. Pearson Product Correlation Coef-

![Figure 2. 2D Measurements of a) Contralateral Pelvic Drop, b) Hip Adduction, and c) Knee Abduction during Midstance](image)
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Finally, the 2D measure of CPD demonstrated a strong correlation to the 2D assessment of HADD on both the left (0.801; p=0.0001) and the right (0.746; p=0.0001) extremities. However, no strong correlations were found between the other variables.

Discussion

The purpose of this study was to examine the reliability and validity of 2D analysis of frontal plane kinematics during treadmill running. Although there have been comparisons between 2D and 3D methods in the analysis of knee valgus\textsuperscript{18,22,23} and knee and hip flexion\textsuperscript{24} in the literature, to the authors' knowledge this 2D method for hip and knee variables has not been compared to 3D kinematic assessments during treadmill running. Consistent with this study's hypothesis, the 2D analysis demonstrated excellent intra-rater reliability. The high reliability found in this study for the use of 2D video analysis to measure frontal plane kinematic variables of running performance confirms the consistency of angle measurements obtained by the same tester. This finding is consistent with reported intra-rater reliability of other dynamic movements using 2D motion analysis systems in the literature.\textsuperscript{18,21,24,25}

In regards to validity, the tested hypothesis that there would be a moderate correlation between the frontal plane kinematics of CPD, peak HADD, and peak KABD was partially supported. There was a significant, moderate correlation found bilaterally between 2D and 3D methods for HADD for both male and female runners on the left and the right lower extremity. (Figure 3) Bland Altman plots confirmed there was no systematic shift between 2D and 3D analysis. (Figure 4 and Figure 5) There was not a significant correlation between 2D and 3D assessment of CPD, and there were inconsistent findings on KABD, as only one of the two limbs was correlated. (Table 3)

Table 2. *Intra-rater reliability: Test-retest reliability with a single tester during the stance phase of running*

<table>
<thead>
<tr>
<th>Average Peak 2D Kinematics (in degrees)</th>
<th>ICC Right</th>
<th>ICC Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvic Drop</td>
<td>0.966</td>
<td>0.958</td>
</tr>
<tr>
<td>Hip Adduction</td>
<td>0.951</td>
<td>0.963</td>
</tr>
<tr>
<td>Knee Abduction</td>
<td>0.976</td>
<td>0.955</td>
</tr>
</tbody>
</table>

Table 3. *Means and Pearson Correlation Coefficients for frontal plane variables in the 2D and 3D analyses*

<table>
<thead>
<tr>
<th></th>
<th>2D in deg (SD)</th>
<th>3D in deg (SD)</th>
<th>Pearson Correlation Coefficient</th>
<th>p-value</th>
<th>2D in deg (SD)</th>
<th>3D in deg (SD)</th>
<th>Pearson Correlation Coefficient</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ContraLateral</td>
<td>4.6 (2.1)</td>
<td>5.2 (1.4)</td>
<td>0.333</td>
<td>0.401</td>
<td>4.3 (1.9)</td>
<td>5.7 (2.1)</td>
<td>0.194</td>
<td>0.364</td>
</tr>
<tr>
<td>Pelvic Drop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip Adduction</td>
<td>11.2 (2.7)</td>
<td>14.0 (3.7)</td>
<td>0.623</td>
<td>0.001*</td>
<td>11.8 (2.7)</td>
<td>13.8 (2.5)</td>
<td>0.539</td>
<td>0.007*</td>
</tr>
<tr>
<td>Knee Abduction</td>
<td>2.3 (4.0)</td>
<td>4.5 (3.5)</td>
<td>0.158</td>
<td>0.460</td>
<td>1.3 (2.9)</td>
<td>5.3 (2.9)</td>
<td>0.541</td>
<td>0.006*</td>
</tr>
</tbody>
</table>
Figure 3. *Peak Hip Adduction Angle: 2D vs 3D.* a) Right Leg, b) Left Leg

Figure 4. *Bland-Altman Plots for Hip Adduction.* a) Right Leg, b) Left Leg

Figure 5. *Bland-Altman Plots for Knee Abduction.* a) Right Leg, b) Left Leg
specifically, hip adduction feedback, in male and female recreational runners with PFPS. Following 8 sessions of visual gait re-training, subjects reduced their HADD by 23% (5 degrees) and had significant improvements in pain and function. Collectively, this suggests that HADD is an important kinematic variable to examine in individuals with similar running-related injuries and may be an important variable for further research investigations.

Although the results of this study support the use of 2D video analysis for analyzing HADD in the clinic, consistent significant correlations were not found in the variables of CPD and KABD between the 2D and 3D methods. Similar studies have evaluated the validity of 2D software in the measurement of the FPPA. Willson and Davis’ protocol used for the FPPA measurement was similar to this study’s measurement of KABD. However, this study utilized the midline of the tibiofemoral joint instead of the distal midpoint of the femur for the angle measurement. Mclean and colleagues investigated side step and side jump movements in healthy male and female collegiate basketball players. The authors confirmed that the 2D knee FPPAs were inherently influenced by hip and knee joint rotations in all three dimensions. Between subjects, 2D camera and 3D data correlated well for the side step (r² = 0.58) and side jump (r² = 0.64). Within subjects, 2D camera and 3D data correlated moderately for the side step (r² = 0.25 ± 0.19) and side jump (r² = 0.36 ± 0.27). However, it should be mentioned that the values for knee abduction angle in Mclean and colleague’s study were significantly higher than the values for knee abduction angle found in the current study. Wilson and Davis analyzed the FPPA during SL squats in females with and without PFPS. Findings suggested that the FPPA values during single-leg squats were associated with increased hip adduction (r = 0.32 to 0.38, p < .044) and knee external rotation (r = 0.48 to 0.55, P < .001) across activities. However, the tested theoretical construct that the 2D analysis of FPPA could quantify 3D joint rotations was not supported. Similarly, Olsen and colleagues assessed the effects of a neuromuscular training program in a cohort of healthy females during a step down task and did find changes in FPPA. They concluded that 2D changes were not significantly associated with any specific change in 3D

Clinically, strengthening and neuromuscular re-education protocols used to treat runners with these diagnoses have led to decreases in HADD in addition to improving pain and function. Willy and Davis performed hip abduction and hip external rotation strengthening and movement education specific to the single leg squat in healthy, female runners and reported significant decreases in HADD, CPD, and hip internal rotation during the squatting movement. However, these improvements in squatting biomechanics were not carried over into running, potentially suggesting that movement training and strengthening employed by the authors was not specific enough to running. To that end, Noehren and colleagues investigated the effect of gait training, specifically, hip adduction feedback, in male and female recreational runners with PFPS. Following 8 sessions of visual gait re-training, subjects reduced their HADD by 23% (5 degrees) and had significant improvements in pain and function. Collectively, this suggests that HADD is an important kinematic variable to examine in individuals with similar running-related injuries and may be an important variable for further research investigations.

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To date, no other studies have examined the concurrent validity of the 2D kinematic variable of peak HADD to 3D methods. The HADD has been previously established as an integral kinematic variable to examine in runners. Previously described hip adduction and hip internal rotation in weight bearing resulted in the medial displacement of the knee joint relative to the foot. This leads to tibial abduction and increased foot pronation, resulting in dynamic genu valgus. Based on this pattern of linked abnormal movement patterns, excessive HADD has been previously linked to running-related injuries such as PFPS, ITBS, and tibial stress fracture. With regard to PFPS, Dierks and colleagues evaluated 20 male and 20 female recreational runners and found a link between increased HADD and weak hip abductor strength in runners with PFPS symptoms. Similar findings were found by Noehren and colleagues in a cohort of female runners with PFPS as compared to healthy controls. In addition to increases in peak HADD, the PFPS group also demonstrated increased peak hip internal rotation compared to the control group. With regards to ITBS, Ferber and colleagues examined differences in competitive, female runners with a history of ITBS as compared to healthy, mileage and age-matched controls revealing increased peak HADD, peak knee internal rotation, and greater peak rearfoot invertor moment in the history of ITBS group. Retrospectively, HADD was also found to be one of the three variables of choice in correctly predicting a history of tibial stress fracture in a cohort of adult female distance runners.

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supports the strong association between the variables of CPD and HADD. Since CPD and KABD were not well-correlated to 3D measurements, using the HADD as a means to predict hip weakness, potential running-related injuries, and track progress through strengthening and movement education programs through 2D video analysis may be more efficacious. The ease of use and cost-effectiveness of the 2D video analysis system enhances its potential for injury prediction, prevention, and rehabilitation.

This study has several limitations. First, all running analyses in the current study were performed on a treadmill, which may not be generalizable to overground running. However, research by Riley and colleagues concluded that treadmill gait was qualitatively and quantitatively very similar to overground gait and subtle differences found between the two in terms of kinematics were generally within the normal variability of gait parameters.37 The benefit of treadmill analysis is that it is used to standardize running conditions across subjects.26 Second, it is difficult to substitute 2D measurements for the accuracy and magnitude of the 3D joint rotations during running and other dynamic movements. The current study analyzed the means of 5 trials of each subject’s frontal plane kinematic variables in midstance using the 2D software. However, the 3D means of peak CPD, KABD, and HADD were calculated from 30 trials. To further validate the methodology used to calculate 2D means, the authors performed a pilot study on five randomly-selected subjects. The means of the 30 trials of all three frontal plane variables in the pilot study correlated well with the means taken from the five trials for each subject in the current study, further validating the protocol of this study.

Future research examining 2D video analysis of running biomechanics should utilize a larger sample of male and female participants of varying running abilities, mileage levels, and ages. In addition, the studies should include individuals with lower extremity musculoskeletal dysfunction and running-related injuries to expand the generalizability to populations typically seen in the clinic. Analyses of the validity and reliability of sagittal plane kinematic variables and frontal plane kinematic variables of the lower shank and foot would be useful in
evaluating the clinical utility of the 2D video analysis software. Future directions of research should include exploring gender differences in frontal and sagittal plane kinematic variables evaluated by the 2D software. Finally, a relationship between hip weakness and altered biomechanics during running has been reported in the literature. Research on movement education and strengthening programs have resulted in positive outcomes in improving these abnormal mechanics, increasing strength, decreasing pain, and improving function in runners. However, more robust studies utilizing a comprehensive approach of neuromuscular training, plyometrics, core and proximal strengthening, and long-term gait retraining using 2D software are required to further evaluate the rehabilitative potential of such strategies for injured runners.

Conclusion
In conclusion, this study identified a moderate correlation in maximum HADD in both extremities of male and female collegiate runners between 2D software and 3D analysis, partially supporting the concurrent validity of the 2D analysis system. No significant correlation was found bilaterally between the two motion analysis systems regarding to CPD and KABD. In addition, the excellent intra-rater reliability found in the current study suggests that the 2D software can accurately be used to examine changes in a patient’s running mechanics from the initial evaluation through the interim assessments by the same evaluator. Based on these results, clinicians utilizing 2D software may have improved confidence regarding describing HADD during clinically based running gait assessments when the 3D “gold standard” software is unavailable. Over all, this study serves as a strong foundation for future research in the utility of 2D video analysis software in accurately examining and treating injured runners for both clinical and research purposes.

REFERENCES


ABSTRACT

Introduction: In clinical practice, joint kinematics during running are primarily quantified by two-dimensional (2D) video recordings and motion-analysis software. The applicability of this approach depends on the clinicians' ability to quantify kinematics in a reliable manner. The reliability of quantifying knee- and hip angles at foot strike is uninvestigated.

Objective: To investigate the intra- and inter-rater reliability within and between days of clinicians' ability to quantify the knee- and hip angles at foot strike during running.

Methods: Eighteen recreational runners were recorded twice using a clinical 2D video setup during treadmill running. Two blinded raters quantified joint angles on each video twice with freeware motion analysis software (Kinovea 0.8.15)

Results: The range from the lower prediction limit to the upper prediction limit of the 95% prediction interval varied three to eight degrees (within day) and nine to 14 degrees (between day) for the knee angles. Similarly, the hip angles varied three to seven degrees (within day) and nine to 11 degrees (between day).

Conclusion: The intra- and inter rater reliability of within and between day quantifications of the knee- and hip angle based on a clinical 2D video setup is sufficient to encourage clinicians to keep using 2D motion analysis techniques in clinical practice to quantify the knee- and hip angles in healthy runners. However, the interpretation should include critical evaluation of the physical set-up of the 2D motion analysis system prior to the recordings and conclusions should take measurement variations (3-8 degrees and 9-14 degrees for within and between day, respectively) into account.

Level of evidence: 3

Key words: kinematics; knee- and hip angles; motion-analysis software; reliability; running
INTRODUCTION

The popularity of running has increased remarkably the past 40 years. The major advances of health benefits attributed to physical activity in general and to running particularly, covers reduced risk of certain chronic disorders and lifestyle diseases (e.g., osteoarthritis, osteoporosis, cardiovascular disease, diabetes, cancer, hypertension, obesity and depression) and increased quality of life. Thus, physical activity has a positive effect on the general costs in the healthcare system and the main national productivity. Unfortunately, running-related injuries (RRI) have been reported as the main reason to a permanent stop of participation in running, with an extraordinary high annual cumulative injury incidence proportion up to 85% in a general running population. The etiology of RRI is, therefore, important to understand in order to establish sufficient prevention strategies and decrease the frequency and the impact of injuries.

Biomechanically, it has been suggested that knee- and hip joint kinematics and kinetics during running are associated with the development of RRI. Furthermore, the risk of sustaining knee and hip injuries might be increased by shod runners utilizing a rear-foot strike compared to using a fore-foot strike and since rear-foot striking is the most utilized striking strategy among runners, the biomechanical impact of the knee- and hip joint during rear-foot striking are of particular interest in relation to RRI.

Milner et al. 2007 suggested that smaller knee flexion at initial contact (IC) among rear-foot strikers contributed to bony injuries because of higher joint stiffness at IC and consequently higher loading rates and impaired shock absorption. Additionally, it has been reported that the peak knee flexion at midstance increased among rear-foot strikers resulting in increased knee extensor joint moments during the continued stride with a potential increased risk of RRI. Furthermore, rear-foot striking is typically linked with increased stride length as compared to mid and fore-foot striking, resulting in increased sagittal peak hip flexion during stance and subsequent increased hip joint moments and potential for increased risk of RRI. Conversely, fore-foot striking might result in higher risk of injuries in the foot and calf since this running pattern involves increased ankle plantar flexion at initial contact and consequently increases the eccentric foot plantar flexor load.

Three-dimensional (3D) motion analysis systems are considered the most accurate and precise methods for analyses of human movements. However, the methodology is time consuming, expensive and consequently, less suitable for field research and clinical use. In contrast, 2-dimensional (2D) video-based assessment techniques are cheaper and easy-to-handle and therefore have been emphasized in clinical practice for analyzing joint kinematics during running. Notwithstanding the obvious advantages, caution should be taken when 2D video-based methods are used to quantify dynamic human movements since the validity of the measurements are challenged by reduction of the description of kinematic parameters being limited to two planes.

It is well known that the utility of any assessment tool depends on its validity and reliability and thus, focus on the validity of 2D video-based motion analyses techniques compared to 3D motion analysis systems in relation to measurements of joint angles has been addressed in previous studies. In general, these studies showed promising results for the validity of the 2D assessment technique. This is supported in a recent study by Ugbolue et al. that investigated the validity of an augmented-video-based-portable-system (AVPS) based on 2D motion analysis and its potential use as a clinical assessment tool during walking. Using a 3D motion analysis system as a gold standard and a two segment goniometric rig as a reference, the accuracy of joint angles measured by the 2D motion analysis technique was tested on 1) the knee joint angle at IC and at terminal contact (TC) and 2) the tibia inclination angle at IC, foot flat (FF), mid-stance (MS) and at TC. No significant differences were found between AVPS and the 3D motion analysis system (P = 0.206), and between the AVPS and the two segment goniometric rig (P = 0.578).

These results should be interpreted with caution in relation to running, since the validity of the 2D motion analysis techniques were measured during walking gait. However, to the authors’ knowledge the validity of the 2D motion analysis technique in relation to running still remains uninvestigated. Validity implies that measurements are relatively free from
error and are highly dependent on the premise that any measurement must be reliable in order to be valid.\textsuperscript{23}

Reliability of the 2D motion analysis technique has previously been investigated in relation to different sports\textsuperscript{22,24-28} and relative to the foot strike pattern in running\textsuperscript{12}, but the reliability of the method in relation to quantification of the knee- and hip angles in running has not been reported. Therefore, the aim of the present study was to investigate the intra- and inter-rater reliability of the within- and between day quantification of the knee- and hip angles recorded in the sagittal plane in recreational runners by a clinical 2D video setup and freeware motion-analysis software.

**METHODS**

**Participants**

Twenty-five healthy recreational runners (13 women, 12 males, 35 ± 9 years, height 175.8 ± 10.5 cm and body weight 76.6 ± 19 kg), without lower extremity injuries three months preceding baseline, volunteered to participate and they were enrolled in the period July to September 2012. The Local Ethical Committee evaluated the study protocol and waived the request of ethics approval since the study design was observational. The local data protection agency approved the project. All the participants provided informed consent.

**Video recordings**

A high-speed video camera (Exilim EX-F1, Casio, Tokyo, Japan, resolution 512x384 pixels at 300 frames per second (fps) and shutter-speed at 1/2000 second) was mounted on a self-constructed welded stationary stand to ensure a standardized height of the camera lens, 86 centimeter above the floor. The stationary stand was located at a distance of 1.5 meters to the treadmill with the optical axis perpendicular to the plane of movement and covering the field of the runner on the treadmill in the sagittal plane.

All recordings were obtained while the participants were running on a commercially available treadmill (Run Xt Pro 600, model D390, Technogym, Italy) illuminated by a 500W halogen lamp. (XH, model HY-150S, 500W, Yuyao Xianghua Lighting Co., Ltd., China).

Prior to the recordings, a marker was placed on the runners' tights for identification of the greater trochanter as a reference point to be used in the quantification process of the joint angles. Subsequently, the participants were given time to become familiar with the treadmill until they felt comfortable and were running steadily in their self-selected speed, then a 30-second video was recorded. All participants were recorded twice with a one-week interval between. During the second session, the participants ran at the same pace as during the first session (mean 10.14 ± SD 1.47 km/h) controlled by the display on the treadmill. The participants were running in their own shoes, which were identical during both sessions.

**Video processing**

In two separate sessions, with a minimum of 14 days in between, two blinded raters (experienced physiotherapists familiar with the use of high-speed video as a tool to quantify joint angles in running) independently quantified the knee- and hip angles at specific video frames on each video (see detailed procedure below), using the freeware motion-analysis software Kinovea (version 0.8.15, available for download at: http://www.kinovea.org).

Prior to or during the quantification process, the raters had the opportunity to comment on the eligibility of each video for inclusion if they needed, based on the video quality by means of illumination, blurriness or other image quality factors that could bias the digitalization of the video and thereby, the raters quantification of joint angles. Seven participants were excluded because of low video quality.

Initially, the video time frame, defined as the duration of one frame (0.03 s\(^1\)) for foot strike was identified (see description of Phase one below). Secondly, the knee- and hip angles in the sagittal plane were quantified (see description of Phase two below).

**Phase one**

**Identification of the video time frame for foot strike**

A fixed video time frame was selected on the individual video files for every of the five foot strikes, to ensure that the raters quantified the knee- and hip angles at the same video time frame. Identification
of the fixed video time frame was conducted through a three step procedure: 1) Each video was forwarded 15 seconds into the total video, and then, the two raters independently identified five consecutive video time frames for initial foot strike of left-legged foot strikes. 2) Step 1 was repeated with a minimum of 14 days apart. 3) Based on the four identification sessions (two sessions from each rater) of the foot strike frames, the fixed video time frame for each of the five foot strikes were defined as the median foot strike frame, rounded up to the forthcoming time frame if the median was between two video time frames.

Phase two

Quantification of the knee- and hip angles

In order to establish consistency in the process of quantifying the knee- and hip angles, a consensus-based standardized protocol was developed by the authors as a part of this investigation (unpublished work).

In brief, the standardized protocol involved the procedure for the raters quantification of knee flexion; the relative angle between tibia and femur and their quantification of hip flexion; the absolute angle between the femur and a vertical line perpendicular to the treadmill, through trochanter major of femur (Figure 1) on five consecutive video time frames for foot strike using the fixed video time frame identified during phase one. The joint angles were quantified by measurement functions in Kinovea by four steps: 1. The raters attached a marker on the lateral femoral condyle and the lateral malleolus on the tibia by the “line “ and “cross marker” functions. 2. Using the “angle” function the raters placed a goniometer on the knee centered on the marker denoting the lateral femoral condyle and the spikes were fitted through the greater trochanter and lateral malleolus, respectively. This angle represented the knee flexion angle. 3. A second goniometer was placed on the treadmill vertically below the greater trochanter and the horizontal spike was aligned with the rear edge of the treadmill and the vertical spike was set through the greater trochanter, symbolizing a plumb line. 4. A third goniometer was placed centered on the greater trochanter with one spike fitted through the lateral femoral condyle and one aligned with the plumb line. This angle represented the hip flexion angle. The software associated with Kinovea automatically calculated the angles.

Before the statistical analysis, the dataset was screened for outliers. Five outliers were found between foot strikes; two because the knee- and hip angles were quantified on the opposite leg, one because of typing errors, one because of missing values from a video, displacing the quantification values from the subsequent videos and one because a foot strike was overlooked. The raters were asked to re-quantify these outliers. After this correction, the maximum and the minimum angle values of the five consecutive foot strikes from each video, quantified by each rater were excluded and the remaining 3 angles were averaged.

Statistical analysis

These mean angle values from each rater were compared by using the Bland and Altman’s limits of agreements (LOA). This method can be used to calculate the 95% prediction interval (the range from upper prediction limit to lower prediction limit) and thereby, the size of the random error and to visualize the distribution of the data in relation to assessing agreement within and between raters (systematic error). In all analyses the difference and the size of the variation did not depend systematically on the average (Fig. 2), which is fulfilling the assumption that a reliable

Figure 1. Print screen picture of the quantified angles. Knee flexion: the relative angle between tibia and femur (the green angle). Hip flexion: the absolute angle between the femur and a vertical line perpendicular to the treadmill (the blue angle), through trochanter major of femur (the pink angle)
RESULTS

The analyses were performed within and between raters, both within and between days. This means that the raters' quantification of joint angles was compared within rater on the same video recording of each participant (intra-rater reliability within day) and between rater (inter-rater reliability within day). The between day analyses were performed by comparing two different video recordings of the same participant within raters (intra-rater reliability between day) and between raters (inter-rater reliability between day).

Within day

The 95% prediction interval for the intra-rater reliability varied three to six degrees for both the knee and hip angle. For the inter-rater reliability the range varied from six to eight degrees for the knee angle and three to seven degrees for the hip angle (Table 1).

Between day

The 95% prediction interval for the intra-rater reliability varied nine to 14 degrees for the knee angle and nine to 11 degrees for the hip angle for both the intra-rater and inter-rater reliability (Table 2).

DISCUSSION

The aim of the present study was to investigate the intra- and inter-rater reliability of the within- and between day quantification of the knee- and hip angles recorded in the sagittal plane in recreational runners using a clinical 2D video setup and freeware motion-analysis software.

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Table 1. Within day measurements

<table>
<thead>
<tr>
<th></th>
<th>FIRST RUNNING SESSION</th>
<th></th>
<th>SECOND RUNNING SESSION</th>
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<tbody>
<tr>
<td></td>
<td>Knee angle 95% LOA (deg)</td>
<td>Hip angle 95% LOA (deg)</td>
<td>Knee angle 95% LOA (deg)</td>
<td>Hip angle 95% LOA (deg)</td>
</tr>
<tr>
<td>INTRA:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rater A</td>
<td>-1.95; 0.87 (3)</td>
<td>-2.44; 1.05 (3)</td>
<td>-2.10; 1.40 (3)</td>
<td>-0.94; 1.77 (3)</td>
</tr>
<tr>
<td>Rater B</td>
<td>-2.94; 3.05 (6)</td>
<td>-3.04; 3.16 (6)</td>
<td>-1.10; 2.36 (3)</td>
<td>-1.86; 1.69 (3)</td>
</tr>
<tr>
<td>INTER:</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>A versus B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st quantification session</td>
<td>-5.59; 2.24 (8)</td>
<td>-5.15; 1.90 (7)</td>
<td>-4.25; 2.31 (7)</td>
<td>-2.52; 2.70 (5)</td>
</tr>
<tr>
<td>2nd quantification session</td>
<td>-4.50; 2.86 (7)</td>
<td>-3.54; 1.74 (5)</td>
<td>-2.98; 2.92 (6)</td>
<td>-1.92; 1.62 (3)</td>
</tr>
</tbody>
</table>

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Method (here the 2D motion analysis technique) must have a reasonably constant variation (standard deviation) throughout the range of measurements. All statistical analyses were performed in STATA statistical package (Stata Corp., 2011, Stata Statistical Software: Release 12, College Station, Texas, USA) and considered statistically significant at \( \alpha < 0.05 \).
by two differences raters with different personally characteristics. In relation to latter, the variability in the between day quantifications were likely to vary more than the within day quantification due to the fact that the quantifications were done on two different video files from the same participant.

**Methodology**

2D camera setups and freeware motion-analysis software have easy applicability and are feasible methods reflecting a clinical setup that may be usable instead of advanced motion-capture methods based on 3D kinematics and force plate quantifications. However, 2D approaches are challenged in maintaining control of the instrumental factors essential for high-quality video recordings, like calibration angles, distance to the runner etc. The quality of video recordings are dependent upon sufficient illumination to overcome picture quality deficits when recording high velocity movements as running using high-speed video cameras with high shutter speeds. The pixilation that occurs in standard camera recordings at 300 fps can additionally influence blurriness. In the present study seven videos were rated as ineligible for quantification because of poor video quality and, therefore, these videos were excluded from the analyses. However, this decision must be considered as a limitation of the study, since

**Quantification of the knee- and hip angle**

The 95% prediction intervals varied from three to eight degrees for the within day analyses and nine to 14 degrees for the between day analyses. It remains unknown if these intervals, indicating the size of the differences between the ratings, are clinically relevant and thereby affect the possibility of quantifying joint angles in clinical practice by 2D motion analyses techniques. However, when comparing the current result with the results from the study by Ugbolou et al 2013, similar variations (7.6 to 10.4 degrees) were observed in their measurements of the knee angle at initial contact and larger variations (16.8 to 28 degrees) in their measurements of the knee angle at TC done by the AVPS (a 2D motion analysis technique), although they found no significant differences between the AVPS and the 3D motion analysis system and between the AVPS and the two segment goniometric rig, respectively.

It is worth mentioning that measurement variation of any measurements or measurement tools, in general, is more likely to be detected than no variation, since the nature of reality is such that measurements are rarely perfectly reliable owing to the multifactorial sources to variation that exist within the total measurement system. As such, generating results with no measurement variation and, thereby, showing perfectly reliability would be fairly impossible. The most relevant components causing the measurement variation found in the present study are mainly attributed to human factors (intra- and inter rater factors) and to the time depending variation that inevitable exist when variables are measures over time (between day variation). In relation to the former, there is a tendency towards that the inter rater variation is higher than the intra rater variation simply because the quantifications were made

<table>
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<tr>
<th>Table 2. Between day measurements</th>
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<tr>
<td><strong>FIRST RUNNING SESSION 1 versus SECOND RUNNING SESSION 1</strong></td>
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<tr>
<td><strong>INTRA:</strong></td>
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<tr>
<td>Rater A</td>
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<tr>
<td>Rater B</td>
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<tr>
<td><strong>INTER:</strong></td>
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<tr>
<td>A versus B</td>
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<td>B versus A</td>
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</table>
it might have influenced the results. It is, therefore, important to highlight that prior to using 2D motion analysis techniques in clinical practice it is important to evaluate the clinical surroundings and the overall set-up.

As a reference point in the quantification process of the joint angles a hip marker was used to identify the joint center of motion. This is a practical method, although it’s accuracy is sensitive to skin artifacts and movements of the runners’ tights. Based on pilot-studies it was obvious, however, that this method would increase the reliability. No standardized guidelines exist in order to increase reliability of the use of 2D video methods and motion-analysis software by clinicians for the purpose of quantifying joint angles. One strength of the present study is, therefore, the development of the standardized protocol based on consensus discussions to enhance the quantifications of joint angles and represents the best available approach to provide consistency in the quantification process.

On the basis of the results from the present study the authors encourage clinicians to keep using 2D motion analysis techniques in clinical practice in order to quantify the knee- and hip angles in healthy runners. However, the interpretation should include critical evaluation of the physical set-up and the 2D video set-up prior to the recordings and conclusions should take measurement variations established in the current study into account.

CONCLUSION
The intra- and inter rater reliability of within and between day quantifications of the knee- and hip angle based on a clinical 2D video setup is sufficient to encourage clinicians to keep using 2D motion analysis techniques in clinical practice to quantify the knee- and hip angles in healthy runners. However, the interpretation should include critical evaluation of the physical set-up of the 2D motion analysis system prior to the recordings and conclusions should take measurement variations (3-8 degrees and 9-14 degrees for within and between day, respectively) into account.

REFERENCES


ABSTRACT

Background and Purpose: There is limited evidence regarding risk factors for lower extremity overuse bone injury (LEOBI) in collegiate athletes. The purposes of the study were to: 1) determine incidence of LEOBI in selected sports and its impact on athletic participation and ADL, 2) assess risk relationships between LEOBI and selected risk factors, and 3) establish the viability of using calcaneal densitometry as a screening tool to identify risk for LEOBI.

Study Design: Prospective analytical cohort design

Methods: Collegiate athletes in selected sports (swimming/diving, women's soccer, field hockey, cross-country/track) at one university were invited to participate. Consenting athletes completed an initial questionnaire including demographic information, history, and menstrual function. Measurements included height/weight, hip abductor strength, foot posture index, and calcaneal bone mineral density. Athletes were monitored for potential LEOBI for nine months and an algorithm was used to determine if physician referral was required. The primary outcome of interest was the occurrence of physician-diagnosed LEOBI. If LEOBI was diagnosed by the physician, the athlete completed a follow-up visit including a repeat bone mineral density scan. All athletes were invited for a repeat scan at the end of the year and completed a final questionnaire. Athlete demographics were summarized using descriptive statistics and differences in continuous risk factors were analyzed using t-tests and ANOVA. Finally, risk relationships for categorical variables were analyzed using chi-square and relative risk.

Results: 84 athletes (64 female, 20 male) consented to participate. Over the study period, eight athletes (one male, seven females) were diagnosed with LEOBI (LEOBI group), five with stress fractures and three with medial tibial stress syndrome. The other 76 athletes who did not have a diagnosis of LEOBI were placed in the non-LEOBI group. Five of the eight were cross-country/track athletes; no swimming/diving athletes had bone injury. Sport (cross-country/track) had a significant relative risk value of 2.26 (95% CI = 1.18-4.32) for LEOBI. There was no association between LEOBI occurrence and sex, hip abductor strength, body mass index, foot type, and menstrual function. There was no difference in bone mineral density at initial or follow-up measures between LEOBI and non-LEOBI groups (p>.05) when analyzing all athletes. When analyzing ground-based athletes only at follow-up (n=44), athletes with LEOBI had lower bone mineral density of right (p = .05) and left (p =.07) calcaneus. The relative risk for developing LEOBI based on calcaneal bone mineral density below the mean of the study participants was 2.1 (95%CI = 1.09-3.35) on the left and 1.53 (95% CI=.80- 3.06) on the right.

Conclusion: The incidence of LEOBI in this population of athletes was approximately 10%. Risk factors were sport (cross-country/track) and decreased left calcaneal bone mineral density. This study supports the use of calcaneal bone mineral density as a screening measurement for LEOBI risk and suggests the need for further investigation into additional LEOBI risk factors.

Level of evidence: 2

Key words: Bone density, medial tibial stress syndrome, overuse injury, risk, stress fracture
INTRODUCTION

Stress fractures\textsuperscript{1-4} and medial tibial stress syndrome (MTSS)\textsuperscript{5-9} are lower extremity overuse bone injuries (LEOBI) that result from microtrauma to bone. LEOBI is commonly experienced in the athletic population\textsuperscript{2,5,10-13} with evidence suggesting that these conditions adversely affect not only athletic participation\textsuperscript{12-14} but also activities of daily living (ADL).\textsuperscript{15} Furthermore, premenopausal bone fractures including stress fracture increase the risk for future fractures in a woman's life.\textsuperscript{16,17} Presently, the impact of LEOBI on athletic participation and ADL in collegiate athletes is not clearly quantified, and there is an incomplete understanding of the risk factors for the development of LEOBI. Because of this lack of evidence, evidence-based prevention strategies for LEOBI do not currently exist.

Stress fractures involve microstructural bone failure, and recent evidence suggests that MTSS, which presents as pain along the posteromedial border of the distal two-thirds of the tibia, also involves changes in bone tissue.\textsuperscript{6,7,10,19} Lower extremity (LE) stress fracture annual incidence rates in collegiate track and field athletes range from 11\%\textsuperscript{20} to 21\%,\textsuperscript{21} and two studies prospectively examining stress fracture occurrence across multiple collegiate sports reported an annual incidence ranging from 1.9\%\textsuperscript{2} to 3.7\%.\textsuperscript{3} MTSS is a common condition in athletes, especially among runners.\textsuperscript{5,12,13,22} with incidence reported in a range of 4\% - 35\%.\textsuperscript{23,24} In a study of collegiate female athletes across multiple sports, 22\% developed MTSS or stress fracture (tibial or fibular) over the course of a single fall season.\textsuperscript{22}

There is a need for LEOBI risk factor identification in order to develop screening measures and prevention strategies. van Mechelen\textsuperscript{25} proposed a sport injury prevention model involving four steps: (1) identifying the extent of the injury problem, (2) understanding the etiology and mechanism of injury, (3) introducing appropriate preventative measures, and (4) assessing the effectiveness of those measures. In a recent systematic review\textsuperscript{26} of overuse injury prevention, the authors concluded that there is little objective evidence supporting current interventions to prevent LEOBI. One potential reason for this paucity of evidence is that the second step of van Mechelen’s model, understanding the etiology and mechanisms of injury, has been inadequately investigated. Failure to identify risk factors will not allow the shift toward an evidence-based prevention and intervention focus.

The most consistent LEOBI risk finding is that athletes who have a history of a stress fracture or MTSS are at higher risk for the reoccurrence of those conditions.\textsuperscript{10,12,13,22} However, most other evidence pertaining to LEOBI or other LE overuse injury risk factors is relatively weak or conflicting. In a study by Nienmuth et al,\textsuperscript{27} a group of recreational runners reported an association between hip abductor weakness and LE overuse injury including stress fractures and MTSS. This finding of hip abductor weakness was supported by Verrelst et al\textsuperscript{28} for athletes with exertional medial tibial pain. Regarding abnormal foot biomechanics as a risk for LEOBI, some evidence suggests that excessive pronation is a risk factor,\textsuperscript{5,28-34} other evidence suggests excessive supination is a risk factor,\textsuperscript{35,36} and a third group of studies have not supported either as a risk factor.\textsuperscript{8,12,13}

Neely\textsuperscript{37} reported a high body mass index (BMI) was a risk factor for LEOBI in military men and women, but low BMI was only a risk factor for military females. Other investigators have not found any association between body composition and LEOBI.\textsuperscript{22,38,39} Goldberg and Pecora\textsuperscript{2} and Ohta-Fukushima et al\textsuperscript{40} found a relationship between athlete-reported increase in training and stress fracture occurrence. Several investigators have reported that menstrual dysfunction is a risk factor for stress fractures in athletic women,\textsuperscript{4,38,41,42} however, the association of MTSS and menstrual dysfunction has not been substantiated. A risk relationship has been shown between LEOBI and low bone mineral density (BMD) as measured using dual-energy X-ray absorptiometry (DXA).\textsuperscript{7,43} Prouteau et al\textsuperscript{44} used ultrasound densitometry to examine risk of stress fracture in athletic women and found no difference in calcaneal speed of sound (SOS) or broadband ultrasound attenuation (BUA) between those athletes with a history of stress fracture and a control group. As this was a cross-sectional study, the authors did not control for the chronology of stress fracture diagnosis in the injured group. Chatzipapas et al\textsuperscript{45} and Lappe et al\textsuperscript{46} used calcaneal ultrasound to examine risk for stress fracture in military personnel and both found ultrasound density measures to be predictive of stress fracture risk.
In order to prevent and/or more effectively treat LEOBI in the future, a better understanding of its risk factors is crucial. Therefore, the authors established three purposes for this study: 1) to determine the incidence of LEOBI over one academic year in selected intercollegiate sports with confirmatory medical diagnoses and describe the impact of LEOBI on athletic participation and ADL (specifically walking and stair climbing), 2) to assess risk relationships between LEOBI and selected potential modifiable risk factors including hip abductor strength, foot type, body mass index (BMI), changes in training, calcaneal bone density, history of LEOBI, and menstrual function, and 3) establish the viability of using calcaneal densitometry as a screening tool for LEOBI.

METHODS
This study was approved by the Saint Louis University Institutional Review Board. It was a prospective analytical cohort design in which collegiate athletes in selected sports at one National Collegiate Athletic Association (NCAA) Division I university were followed for one academic year (August 2012 to May 2013). Sports were selected based on highest occurrence of LEOBI as recorded in the university intercollegiate athletic injury reports from the previous two years. Research team members attended team meetings for selected teams, described the research study to athletes, and answered any questions pertaining to the study. Athletes who elected to participate in the research study completed informed consent.

Participants
Athletes on the swimming/diving team, women’s soccer team, field hockey team, and cross-country/track team (including running and field events) were invited to participate. Participants were between 18 and 23 years of age and were free of current lower extremity injury. Exclusion criteria consisted of: 1) age less than 18 years, 2) not a member of the swimming/diving, women’s soccer, field hockey or cross-country/track teams, 3) unable to perform double limb stance with symmetrical weight-bearing.

Procedures
Risk factor data was collected on all participants prior to the start of the 2012-2013 fall season. Participants were monitored over the academic year for the development of LEOBI. Participants received monthly email reminders asking them to report any lower extremity pain to their team athletic trainer (AT). At the end of the study period, two groups were formed, participants with LEOBI and participants without LEOBI during the academic year.

Preseason Questionnaire
Participants completed a web-based questionnaire including gender, academic collegiate year, athletic collegiate year, sport, use of foot orthotics, lifetime history of diagnosed lower extremity stress fracture, history of medial leg pain in the last 12 months, and for women, menstrual function history.

Height and Weight
A standard scale was used to measure weight (pounds) and a wall-mounted tape measure was used to measure height (inches). BMI (kg/m²) was calculated using the height and weight measures converted to the metric system.

Isometric Hip Abductor Strength
Hand-held dynamometry (Microfet, Hogan Industries, Draper, UT) was used to measure bilateral isometric hip abductor strength in sidelying using the standard muscle testing position described by Kendall. Randomization of the initial test leg was determined by coin flip. Participants were then placed in sidelying and the test leg placed into 30 degrees of hip abduction. The tester stabilized the hip proximally at the iliac crest and provided an adduction force at the knee approximately two cm proximal to the lateral epicondyle. The break-test method was used to elicit a maximal effort with the tester blinded to the force being produced during the test. The muscle contraction was performed for two seconds and repeated two times, with a 30 second rest period between each effort. The average force (in Newtons) was calculated for the two trials.

Foot Posture Index
The Foot Posture Index – 6 (FPI-6) is a criterion based visual assessment of midfoot, forefoot, and rearfoot posture, and has been used in other studies examining the relationship of foot posture and injury. Six regions of the foot are scored using a 5-point Likert scale and summed to provide a com-
posite score with lower numbers reflecting a more supinated foot and higher numbers a more pronated foot. The FPI-6 was performed with the subject in relaxed double limb stance with symmetrical weight bearing with their arms at their side and head in neutral. The examiner moved around the subject based on the region of the foot being assessed and a score was recorded. The composite score was calculated and used to classify foot posture categorically as: highly pronated, pronated, neutral, supinated, or highly supinated.

**Calcaneal Densitometry**

Calcaneal bone mineral density (cBMD) was determined quantitatively using the Sahara clinical bone sonometer (Hologic, Inc, Waltham, MA). The authors chose to examine cBMD using ultrasound densitometry for three reasons. First, there is no exposure to ionizing radiation with this measurement unlike DXA, an important consideration when studying a young adult population. Second, the ultrasound densitometer is a relatively inexpensive and portable device which requires minimal operator training and minimal time to use. Third, ultrasound densitometry has been shown to have similar prediction capability for fracture risk as compared to DXA.54-56

Prior to each day of testing, calibration of the densitometer was assessed as described by manufacturer guidelines. The tester then applied an oil based coupling gel (Hologic, Inc.) to both transducer pads. Participants were seated in a straight-back chair approximately 12-18 inches from the scanner and the bilateral heels were inspected for abrasions or open sores. The tester cleaned the sides of the heels with a towelette and dried the heel prior to testing. The subject's foot was then placed into the foot well with the heel firmly in the heel cup and the foot aligned with the positioning line located between the second and third toe. The positioning aid was then lowered and the subject's leg position adjusted to within two finger widths between the anterior tibia and positioning aid. The positioning aid was firmly secured to the leg with a strap and the subject was instructed to remain still during the test. The subject's heel placement was checked to ensure proper placement and the measurement was then initiated. The transducer pads moved to the measurement position and the measurement was completed in less than 10 seconds. Speed of sound (m/s) and an estimate of the subject's cBMD (g/cm²) was calculated by the unit. The measures were recorded and the steps were repeated for the subject's opposite heel.

**LEOBI Diagnosis**

The LEOBI diagnostic process involved the team athletic trainers (AT) and one designated university sports medicine physician who was a member of the research team. Participants with symptoms suggestive of LEOBI as determined by the team athletic trainer were asked to rate their pain using the Nirschl scale (Table 1).57 Referral to the physician was based on the following algorithm: 1) athletes without LEOBI history presenting with Nirschl Levels 1-3 pain (pain not interfering with activity) suggestive of LEOBI were monitored and routine interventions were provided by the AT; 2) athletes with a history of LEOBI presenting with Nirschl Levels 1-3 pain suggestive of a new occurrence of LEOBI received routine interventions by the AT and were referred to the physician; 3) athletes presenting with Nirschl Levels 4-7 (pain interfering with activity) suggestive of LEOBI received routine interventions provided by the AT and were referred to the physician.

The physician performed an examination of the referred athletes to establish a medical diagnosis for the athlete's condition. The clinical criteria for diagnosis of medial tibial stress syndrome and stress fracture were based on Kortebein et al58 and physician-selected provocative tests (Table 2). Examination by the physician included radiographs, bone scans, and/or MRI if indicated based on standard care.

**Follow-Up of Athletes Diagnosed with LEOBI**

Athletes diagnosed with LEOBI by the physician were asked to participate in a brief follow-up exam with a member of the research team. The follow-up was scheduled within a week of diagnosis and included a structured interview with the athlete with questions regarding training changes prior to the injury diagnosis and the impact LEOBI had on daily activities and athletic participation. Female athletes were queried regarding changes in menstrual function. Repeat calcaneal ultrasound densitometry also was performed at this time on all athletes diagnosed with LEOBI.
All athletes were asked to participate in repeat calcaneal densitometry at the end of the academic year unless they had undergone a measurement within the past three months. At the time of repeat measurement, athletes were asked to complete a final questionnaire that included sport, use of foot orthotics, occurrence of medial leg pain over the past academic year, and for women, menstrual function over the past academic year.

Data Analysis
The primary outcome of interest was the occurrence of diagnosed LEOBI. Overall participant demographics were analyzed using descriptive statistics with breakdown by percentage of all athletes and by sport. Incidence rates of LEOBI during the academic year were calculated for all athletes and by sport. Potential risk relationships were investigated using independent t-tests or ANOVA for continuous measures which included quantitative BMI, hip abductor strength, cBMD, and SOS. Chi-square was used to analyze categorical measures including sex, sport, categorical BMI, FPI-6, previous LEOBI, and menstrual function. Relative risk for LEOBI was calculated using 2x2 contingency tables with LEOBI/no-LEOBI cross-tabulated with bivariate potential risk factors. Data pertaining to changes in training and the effect of LEOBI on sport participation and

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**Table 1. Nirschl Rating Scale**

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>Stiffness or mild soreness after specific sport activity. Pain is usually gone within 24 hours.</td>
</tr>
<tr>
<td>Level 2</td>
<td>Stiffness or mild soreness before specific sport activity that is relieved by warm-up. Symptoms are not present during specific sport activity, but return afterward, lasting up to 48 hours.</td>
</tr>
<tr>
<td>Level 3</td>
<td>Stiffness or mild soreness before specific sport activity. Pain is partially relieved by warm-up, is minimally present during activity, but does not interfere with the activity.</td>
</tr>
<tr>
<td>Level 4</td>
<td>Similar to Level 3 pain but more intense. Pain interferes with activity causing the athlete to alter training or performance of the sport. Mild pain occurs with activities of daily living, but does not cause a major change in them.</td>
</tr>
<tr>
<td>Level 5</td>
<td>Significant (moderate or greater) pain before, during, and after activity, causing alteration of activity. Pain occurs with activities of daily living (walking, stair climbing), but does not cause a major change in them.</td>
</tr>
<tr>
<td>Level 6</td>
<td>Level 5 pain that persists even with complete rest. Pain disrupts simple activities of daily living.</td>
</tr>
<tr>
<td>Level 7</td>
<td>Level 6 pain that also disrupts sleep consistently. Pain is aching in nature and intensifies with activity.</td>
</tr>
</tbody>
</table>

**Table 2. Medial Tibial Stress Syndrome and Stress Fracture Differential Diagnosis**

<table>
<thead>
<tr>
<th>Presentation</th>
<th>Medial Tibial Stress Syndrome</th>
<th>Stress Fracture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exam</td>
<td>Diffuse tenderness along posteromedial tibia</td>
<td>Focal tenderness</td>
</tr>
<tr>
<td></td>
<td>No focal percussion pain</td>
<td>Focal percussion pain present</td>
</tr>
<tr>
<td></td>
<td>No distant percussion pain</td>
<td>Distant percussion pain present</td>
</tr>
<tr>
<td></td>
<td>Provocative tests* negative</td>
<td>Provocative tests* positive</td>
</tr>
<tr>
<td></td>
<td>Neurovascular evaluation normal</td>
<td>Neurovascular evaluation normal</td>
</tr>
</tbody>
</table>

*Tuning fork, single leg hop, fulcrum test
ADL acquired in interviews of athletes with diagnosed LEOBI were summarized by frequency counts. Although efforts were made to collect all data points from all participants, if there were missing data, the analyses were conducted with a smaller sample size.

Reliability
To assess the reliability of the calcaneal densitometry (SOS, cBMD), the field hockey team was randomly selected to have repeated density measures of both feet at time of initial data collection. For FPI-6 reliability, the FPI-6 of 15 volunteers was assessed with the tester blinded to name and person and could only visualize the lower leg and foot. Volunteers were then presented in random order for a second assessment of FPI-6. Intrarater reliability was calculated using intraclass correlation coefficients (3,1) for cBMD and FPI-6. SPSS version 20.0 (Chicago, IL) was used for all data management and analysis.

RESULTS
A total of 150 intercollegiate athletes from four sports were invited to participate in the study, and 84 (56%) completed informed consent. Of the 84 athletes who completed initial testing, 54 (64%) returned for follow-up testing in May 2013. Athletes were contacted multiple times and provided with multiple data collection times to encourage follow-up. Reasons for non-participation in follow-up were unknown. All data points were collected on all 84 athletes at initial visit except cBMD for one athlete was not collected because of narrow heel size. All data points were collected on all 54 athletes at time of follow-up. Participant demographics are summarized in Table 3. Mean BMI was significantly different between sport teams (Table 4); athletes on the cross-country/track team had significantly lower BMI than those on the field hockey and swimming/diving teams.

Over the academic year, eight of the 84 athletes (9.5%) were diagnosed with LEOBI; five with stress fractures (one metatarsal, two tibial, one femoral, and one pubic ramus) and three with MTSS. No swimming/diving athletes were diagnosed with LEOBI; five of the athletes with LEOBI were cross-country/track athletes, two were soccer athletes, and one was a field hockey athlete. A 2 x 2 contingency table (Table 5) between sport (cross-country/track, not cross-country/track) and LEOBI occurrence revealed a significant relative risk value of 2.26 (95% CI = 1.18-4.32) for the development of LEOBI in cross-country/track athletes. There was no significant association between the development of LEOBI and sex (p=.43), BMI (p=.51), foot type (R p=.10, L p=.76), hip abductor strength (R p=.28, L p=.61), and menstrual function during the study period (p=.57) in this group of athletes. Also, there was no significant association between the occurrence of LEOBI and a history of exercise-related leg pain (ERLP) over the past 12 months (p=.12) or a history of stress fracture (p=.43). Of the eight athletes with confirmed LEOBI, three athletes were unable to participate in practice or competition following injury for a week or greater, and only one of those reported that their LEOBI interfered with ADL.

The calcaneal densitometer measures (SOS, cBMD) for all athletes at the initial and follow-up visit showed no significant difference (p>.05) between the athletes who did and did not develop LEOBI,
found that the swimming/diving and field hockey teams had significantly lower calcaneal densitometer measures than the women’s soccer and cross-country/track teams.

As swimming/diving athletes had significantly lower cBMD and SOS bilaterally than the other three teams (p < .005), less dry-land training as compared to previous years, and no occurrence of LEOBI during the academic year, the calcaneal densitometer measures were analyzed (SOS, cBMD) for the sports that were ground-based (cross-country/track, field hockey, women’s soccer). This analysis revealed a significantly lower R cBMD in the LEOBI group (p = .05), and a trend towards decreased L cBMD in the LEOBI group (p = .07) at the follow-up measure (Table 8). To examine risk of developing LEOBI based on cBMD, the authors dichotomized the ground-

Although there was a trend towards decreased SOS and cBMD values in the athletes who developed LEOBI at both measurement times (Table 6). Comparison of calcaneal densitometer measures (SOS, cBMD) across the four sport teams using a one-way ANOVA was significant, with the swimming/diving team showing the lowest density measures (Table 7). Using post-hoc Tukey LSD analysis, the authors

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**Table 4. BMI (mean and categorical) by sport**

<table>
<thead>
<tr>
<th>Sport</th>
<th>Mean BMI (kg/m²)</th>
<th>Underweight (&lt; 18.5 kg/m²)</th>
<th>Normal (18.5-24.9 kg/m²)</th>
<th>Overweight (25.0-29.9 kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field Hockey</td>
<td>23.29</td>
<td>0</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>Soccer</td>
<td>22.14</td>
<td>0</td>
<td>22</td>
<td>2</td>
</tr>
<tr>
<td>Swimming/Diving</td>
<td>23.22</td>
<td>0</td>
<td>14</td>
<td>5</td>
</tr>
<tr>
<td>Cross-Country/Track</td>
<td>20.97</td>
<td>3</td>
<td>22</td>
<td>1</td>
</tr>
<tr>
<td>ALL</td>
<td>22.23</td>
<td>3</td>
<td>70</td>
<td>11</td>
</tr>
</tbody>
</table>

*aSignificantly lower than field hockey and swimming/diving (p < .05)*

---

**Table 5. 2 x 2 Contingency Table (Sport x LEOBI)**

<table>
<thead>
<tr>
<th>Sport</th>
<th>LEOBI</th>
<th>No-LEOBI</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>XC/Track</td>
<td>5</td>
<td>21</td>
<td>26</td>
</tr>
<tr>
<td>Not XC/Track</td>
<td>3</td>
<td>55</td>
<td>58</td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>76</td>
<td>84</td>
</tr>
</tbody>
</table>

LEOBI=lower extremity overuse bone injury
XC=Cross-country
Chi-square=4.12 (p=.042); RR=2.26 (95% CI=1.18 – 4.32)

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**Table 6. Initial (n=84) and follow-up (n=54) calcaneal densitometry measures by group**

<table>
<thead>
<tr>
<th>Measure</th>
<th>LEOBI Group (Mean ± SD)</th>
<th>No-LEOBI Group (Mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R SOS (Initial)</td>
<td>1595.0 ± 25.5</td>
<td>1606.3 ± 37.1</td>
</tr>
<tr>
<td>L SOS (Initial)</td>
<td>1597.4 ± 38.5</td>
<td>1605.0 ± 33.1</td>
</tr>
<tr>
<td>R cBMD (Initial)</td>
<td>.661 ± .119</td>
<td>.715 ± .152</td>
</tr>
<tr>
<td>L cBMD (Initial)</td>
<td>.645 ± .137</td>
<td>.704 ± .141</td>
</tr>
<tr>
<td>R SOS (Follow-up)</td>
<td>1587.1 ± 29.9</td>
<td>1603.3 ± 33.6</td>
</tr>
<tr>
<td>L SOS (Follow-up)</td>
<td>1593.2 ± 33.7</td>
<td>1605.0 ± 31.7</td>
</tr>
<tr>
<td>R cBMD (Follow-up)</td>
<td>.619 ± .140</td>
<td>.694 ± .130</td>
</tr>
<tr>
<td>L cBMD (Follow-up)</td>
<td>.649 ± .150</td>
<td>.715 ± .137</td>
</tr>
</tbody>
</table>

LEOBI=lower extremity overuse bone injury
SOS= Speed of sound (m/s), cBMD= calcaneal bone mineral density (g/cm²)
All p values > 0.05
The intratester correlation coefficient value (ICC 3,1) for the FPI-6 was .82 (95% CI .61-.92) aggregated across both feet.

**DISCUSSION**

The first purpose of this study was to quantify the incidence of LEOBI in a select group of collegiate athletes during an academic year with confirmatory medical diagnosis, and to describe the impact of the ground-based athletes into two groups for each foot, those with cBMD greater than or equal to the ground-based athletes group mean, and those with cBMD below the ground-based athletes group mean. The relative risk for developing LEOBI based on L cBMD below the group mean was 2.1 (95% CI = 1.09-3.35) and based on R cBMD below the group mean was 1.53 (95% CI = .80-3.06).

From the cBMD reliability study (Table 9), the intraclass correlation coefficient values (ICC 3,1) were all greater than 0.95, indicating a high level of measurement consistency. The intratester correlation coefficient value (ICC 3,1) for the FPI-6 was .82 (95% CI .61-.92) aggregated across both feet.

**Table 7. Bone densitometry measures by sport**

<table>
<thead>
<tr>
<th>Sport</th>
<th>R SOS</th>
<th>L SOS</th>
<th>R cBMD</th>
<th>L cBMD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field Hockey</td>
<td>1594.8 ± 26.8</td>
<td>1600.7 ± 24.6</td>
<td>.667 ± .110</td>
<td>.687 ± .098</td>
</tr>
<tr>
<td>Soccer</td>
<td>1625.8 ± 40.3</td>
<td>1619.1 ± 37.8</td>
<td>.786 ± .179</td>
<td>.758 ± .169</td>
</tr>
<tr>
<td>Swimming/Diving</td>
<td>1580.7 ± 27.9a</td>
<td>1579.9 ± 20.7a</td>
<td>.627 ± .115b</td>
<td>.610 ± .084b</td>
</tr>
<tr>
<td>XC/Track</td>
<td>1610.8 ± 30.8</td>
<td>1610.5 ± 32.3</td>
<td>.729 ± .128</td>
<td>.714 ± .141</td>
</tr>
</tbody>
</table>

SOS= Speed of sound (m/s), cBMD= calcaneal bone mineral density (g/cm²)

XC=Cross-country

R SOS F=7.44 (p=.000); L SOS F=6.30 (p=.001)

R cBMD F=5.18 (p=.003); L cBMD F=4.54 (p=.005)

aSignificantly lower than soccer and cross-country/track (p<.05)

bSignificantly lower than soccer (p<.05)

**Table 8. Initial and follow-up bone densitometry measures of ground-based athletes by group (n = 64 athletes at initial, n=44 at follow-up)**

<table>
<thead>
<tr>
<th>Measure</th>
<th>LEOBI Group (Mean ± SD)</th>
<th>Non-LEOBI Group (Mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R SOS (Initial)</td>
<td>1595.0 ± 25.5</td>
<td>1615.0 ± 35.9</td>
</tr>
<tr>
<td>L SOS (Initial)</td>
<td>1597.4 ± 38.5</td>
<td>1613.4 ± 32.3</td>
</tr>
<tr>
<td>R cBMD (Initial)</td>
<td>.661 ± .119</td>
<td>.745 ± .151</td>
</tr>
<tr>
<td>L cBMD (Initial)</td>
<td>.645 ± .137</td>
<td>.735 ± .143</td>
</tr>
<tr>
<td>R SOS (Follow-up)</td>
<td>1587.1 ± 29.9</td>
<td>1610.3 ± 32.9</td>
</tr>
<tr>
<td>L SOS (Follow-up)</td>
<td>1593.2 ± 33.7</td>
<td>1612.0 ± 30.0</td>
</tr>
<tr>
<td>R cBMD (Follow-up)</td>
<td>.619 ± .140</td>
<td>.722 ± .127</td>
</tr>
<tr>
<td>L cBMD (Follow-up)</td>
<td>.649 ± .150</td>
<td>.745 ± .129</td>
</tr>
</tbody>
</table>

LEOBI=lower extremity overuse bone injury

SOS= Speed of sound (m/s), cBMD= calcaneal bone mineral density (g/cm²)

a p>.05

b p=.05

c p=.07

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LEOBI on sport and ADL. Ten percent of athletes developed LEOBI over the academic year, five with stress fractures and three with MTSS, and all were female except one. The incidence of stress fracture in this study (5/84 = 6%) across all four sports was slightly higher than the previously reported range of 1.9% to 3.7% in a mixed group of collegiate athletes. Among the cross-country/track athletes in the current study, 15% (4/26) developed stress fractures, well within the range of 11% to 21% previously described in college track and field athletes. The incidence of MTSS in this study (3/84 = 3.6%) is on the low end of the incidence range of 4%-35% described in the literature.

In the physician referral algorithm, an athlete either had to have 1) a Nirschl pain rating of 4 or greater, meaning that their LEOBI was interfering with sport participation, or 2) a Nirschl pain rating between 1 and 3 (non-interfering pain) with a history of LEOBI. Of the eight athletes diagnosed with LEOBI by the physician, three were referred to the physician with a Nirschl pain of 4 or greater, and five had a pain rating of less than 4, but had a history of LEOBI. In the latter group, all five athletes reported that the LEOBI pain had either no effect or a minimal effect on sport participation including practice and competition, and none of these athletes had any interference in ADLs. The group of athletes who had a Nirschl pain rating of 4 or greater were all cross-country/track athletes and all reported they were unable to practice or compete in their sport because of LEOBI. Only one of these three athletes reported that LEOBI significantly interfered with ADLs; the other two athletes reported pain with ADLs but no ADL interference.

The second purpose of this investigation was to determine if there was a risk relationship between the occurrence of LEOBI and potential modifiable risk factors. The potential factors selected: hip abductor strength, foot type, BMI, changes in training, previous episode of LEOBI, and menstrual function, were based on the authors' research experience and the evidence summarized in the introduction. In this group of 84 athletes, no significant association was found between the occurrence of LEOBI and hip abductor strength, foot type, BMI, changes in training, previous episode of LEOBI, or menstrual function.

Although two studies have shown an association between hip abductor weakness and overuse injury, this relationship was not found in the current study. Niemuth et al used a hand-held dynamometer to assess hip abductor strength as was done in the current study, but his study population was a group of 30 injured recreational runners and a random group of 30 non-injured runners. Also, Niemuth et al et al defined “injury” to include any lower extremity overuse injury. Verrelst et al used an isokinetic device to measure hip abductor strength in a group of collegiate freshmen female students in physical education and followed them over a three month period for the occurrence of exertional medial tibial pain. Their definition of injury was limited to medial tibial pain associated with exercise. In both studies, subjects were not intercollegiate athletes and the definition of injury differed from the one used in the current study.

The evidence pertaining to the relationship between foot type and LEOBI is conflicting with some studies supporting a risk relationship and others not supporting the relationship. Varying among studies is the specific measurement used to assess foot type including navicular drop, static rearfoot position, medial longitudinal arch, standing foot angle, planar pressure, the FPI-6, and foot kinematics during gait. The authors assessed foot type using the FPI-6, a scoring tool that uses scores observations of the rearfoot, midfoot, and forefoot in order to create a composite score that allows the foot to be classified as highly pronated, pronated, neutral, supinated, or highly supinated. The current results were consistent with those studies that did not find a relationship between foot type and injury, three of which used the FPI-6.

In a narrative review of risk factors for ERLP, Neely reported an association of high or low BMI with ERLP occurrence, but this evidence was drawn from...
in "dry-land" training of the athletes on the swimming/diving team. The authors believe that this had a strong effect on the absence of LEOBI among these athletes. At the follow-up densitometry measurement for the ground-based athletes only, the athletes with LEOBI had a significantly lower cBMD in the R foot (p= .05) and a difference trending toward significance (p= .07) in the L foot. The presence of L cBMD less than the group mean increased the risk of developing LEOBI by two-fold. In spite of the relatively small number of athletes with LEOBI in this pilot work, these data support previous findings that have shown an association between decreased BMD and LEOBI using DXA.7,43 Although Prouteau et al 44 did not find a difference in cBMD or SOS between female athletes with and without a history of stress fracture, they did find a difference in the fractal parameter of trabecular bone. This parameter is an indirect measure of trabecular micro-architecture, and the authors reported that when this parameter was combined with BMI at birth, it correctly identified 85% of female athletes in the stress fracture group. This evidence supports the current finding of a bone difference between those who do and do not develop LEOBI. It is noteworthy, however, that the current study was a prospective cohort design whereas the Proteau et al study44 was cross-sectional and did not control for the time elapsed from stress fracture diagnosis.

The third purpose of the current study was to establish the viability of using calcaneal densitometry as a screening tool for LEOBI. Overall, the cBMD and SOS measures were found to exhibit high reliability. These results, combined with the differences observed in bone density between athletes with and without LEOBI in a small pilot sample, provide support for the use of calcaneal densitometry as a screening tool to identify athletes at risk for LEOBI.

Studies of ERLP in military populations only. In this group of collegiate athletes, BMI was not associated with the incidence of LEOBI, consistent with findings of other studies involving collegiate athletes.22,38

Two of the eight injured athletes in the current study described training changes in the two months preceding the injury diagnosis as "abrupt." While all injured athletes reported an increase in training volume prior to their injury, most athletes (6/8) described the change as a gradual increase in volume. Two previous studies of overuse bone injury in high school and collegiate athletes2,40 reported an association of self-reported increased training volume and stress fracture occurrence. Goldberg and Pecora2 reported that freshman athletes were more at risk for stress fracture occurrence and speculated that the increase in training from high school to college was a causal factor. Only two of the eight injured athletes in the current study were freshman, and one of those reported an abrupt increase in training prior to injury.

Menstrual function in female athletes was not associated with the development of LEOBI in this sample. Of the eight injured athletes, seven were female but only one athlete (14%) reported either amenorrhea or oligomenorrhea in the past year, and three (43%) in their lifetime. Of the non-LEOBI group of female athletes, eight (24%) reported either amenorrhea or oligomenorrhea in the past year, and 17 (30%) in their lifetime. Although the association of menstrual dysfunction and overuse bone injury is well-established,4,38,41,42 the current results did not corroborate with these findings. This difference may be accounted for by the current study’s reliance on self-report of menstrual function as well as the prospective rather than cross-sectional design.

For all athletes, there was no significant difference in cBMD or SOS between LEOBI and no LEOBI groups at the initial measurement and follow-up. However, based on unique circumstances associated with the swimming/diving athletes over the course of the study, the authors decided to examine athletes in ground-based sports separately. In the two years prior to the current study, the swimming/diving team was among the top three teams for numbers of athletes with stress fracture. During the academic year of this study, there was an intentional decrease in “dry-land” training of the athletes on the swimming/diving team. The authors believe that this had a strong effect on the absence of LEOBI among these athletes. At the follow-up densitometry measurement for the ground-based athletes only, the athletes with LEOBI had a significantly lower cBMD in the R foot (p= .05) and a difference trending toward significance (p= .07) in the L foot. The presence of L cBMD less than the group mean increased the risk of developing LEOBI by two-fold. In spite of the relatively small number of athletes with LEOBI in this pilot work, these data support previous findings that have shown an association between decreased BMD and LEOBI using DXA.7,43 Although Prouteau et al44 did not find a difference in cBMD or SOS between female athletes with and without a history of stress fracture, they did find a difference in the fractal parameter of trabecular bone. This parameter is an indirect measure of trabecular micro-architecture, and the authors reported that when this parameter was combined with BMI at birth, it correctly identified 85% of female athletes in the stress fracture group. This evidence supports the current finding of a bone difference between those who do and do not develop LEOBI. It is noteworthy, however, that the current study was a prospective cohort design whereas the Proteau et al study44 was cross-sectional and did not control for the time elapsed from stress fracture diagnosis.

The third purpose of the current study was to establish the viability of using calcaneal densitometry as a screening tool for LEOBI. Overall, the cBMD and SOS measures were found to exhibit high reliability. These results, combined with the differences observed in bone density between athletes with and without LEOBI in a small pilot sample, provide support for the use of calcaneal densitometry as a screening tool to identify athletes at risk for LEOBI.

A history of LEOBI has been shown to be a risk factor for the development of a new occurrence in multiple studies,10,12,13,22 and a recent systematic review of MTSS risk factors24 found a history of MTSS to be one of the strongest risk factors for the development of MTSS. In the initial questionnaire, athletes were queried about both a history of stress fracture and a history of ERLP. Although neither of these contingency tables revealed a statistically significant risk
association, five of the eight injured athletes (62.5%) reported a history of ERLP whereas 34% of the non-injured athletes reported a history of ERLP.

The authors recognize several limitations of the current study. First, the sample of collegiate athletes was limited to athletes in one midwestern NCAA Division I university. Second, although all athletes in the four selected sports were invited to participate, only slightly more than half of those athletes consented to participate. The authors are aware of multiple athletes in the group that did not consent to participate who also presented with LEOBI symptoms, but as these athletes were not consented, no risk data is available for these athletes. Third, the authors relied on the athletes’ self-report of symptoms of LEOBI to the team athletic trainer in order to apply the decision rules pertaining to physician referral and potential LEOBI diagnosis. Fourth, the authors recognize that only a small sample size of athletes were diagnosed with LEOBI over the academic year, limiting statistical power to effectively detect differences. Finally, there are limited data pertaining to calcaneal density in an active collegiate-aged population.

Conclusions
From this pilot work of risk factors for LEOBI in collegiate athletes, the incidence of LEOBI was found to be approximately 10%. The identified risk factors for LEOBI based on significant relative risk values were sport (cross-country/track) and decreased L cBMD. Calcaneal BMD was a relatively stable measure over the nine-month period of study. These pilot data suggest need for further investigation into the predictive property of cBMD screening for LEOBI with a larger and more diverse sample as well as multi-year monitoring. Also, there is a need for additional cBMD data in college-aged individuals who are not intercollegiate athletes for comparison purposes.

REFERENCES


45. Chatzipapas CN, Drosos GI, Kazakos KI, Tripianis G, Iatrou C, Verettas DA. Stress fractures in military


ABSTRACT

Study Design: Observational

Background: The Star Excursion Balance Test (SEBT) is used to evaluate dynamic postural control and screen for injury risk. No prior studies have investigated whether the quality of movement during the SEBT has clinical value and can adequately predict injury.

Purpose: To develop a visual assessment tool and evaluate the relationship between movement quality and SEBT outcomes.

Methods: One hundred healthy subjects were included. Baseline demographic, limb length, and individual SEBT performance data were collected. SEBT outcomes were obtained and used to classify individuals as at-risk or not at-risk. At-risk individuals demonstrated anterior right/left reach distance difference greater than 4 cm, and/or normalized composite reach distance less than 89.6% for males or 94% for females. Three independent reviewers, blinded to SEBT outcomes, assessed the anterior reach test on videotape. Reviewers underwent training on a scoring system to assess movement quality at the trunk, pelvis, and knee. The total score of movement faults was used to determine interrater reliability and calculate sensitivity and specificity, in addition to positive and negative predictive values of SEBT outcome.

Results: Seventy-one subjects were classified as at risk. Interrater reliability of movement scoring was poor-moderate for the trunk and pelvis ($\kappa = 0.18-0.43$), and moderate for the knee ($\kappa = 0.5-0.6$). Rater agreement for total movement score was fair-moderate ($W = 0.64-0.73$). Rater assessment of aberrant movement was not predictive of SEBT performance. However, subjects deemed at risk had fewer movement faults per rater assessment. Raters displayed moderately strong specificity (0.59-0.82) and poor sensitivity (0.14-0.39) in knee assessment to detect at risk performance on the SEBT.

Conclusion: Clinical observation of knee movement demonstrated acceptable interrater reliability and moderately strong specificity to detect at-risk SEBT outcome. Total movement score across all regions demonstrated fair-moderate agreement. Subjects who were at risk tended to have fewer movement faults.

Level of evidence: 3

Key words: Lower extremity, postural stability, Star Excursion Balance Test
INTRODUCTION
The Star Excursion Balance Test (SEBT) is an accepted, low-cost, and reliable instrument used in physical therapy practice as a means of evaluating dynamic postural control. Differences in reach distances between lower limbs on the SEBT have been found to be sensitive in identifying individuals with chronic ankle instability, patellofemoral pain syndrome, anterior cruciate ligament deficiency, and movement discrepancy in those who have undergone anterior cruciate ligament reconstruction (ACL-R). Additionally, the results of the SEBT have been identified as a predictor of injury in high school basketball players and collegiate football athletes; however, it is encouraging for rehabilitation professionals and athletes that SEBT performance can be improved through an appropriate intervention program.

Dynamic postural control is one of numerous intrinsic risk factors for lower extremity injury reported in the literature. Intrinsic risk factors for injury include, but are not limited to: age, sex, flexibility, strength, neuromuscular control deficiencies, muscle imbalances, and injury history. Of these risk factors, history of previous injury is one of the most predictive of future injury. These findings demonstrate the need for appropriate screening measures to identify modifiable injury risk factors in order to implement preventative strategies prior to initial injury, as subsequent injury can often be more devastating than the initial injury.

Neuromuscular control deficiencies including greater knee dynamic valgus and high hip abduction loads during specific standardized tests have identified athletes who may be at risk for future injury. Body region-specific movement assessments, such as kinematic analysis to quantify frontal plane knee motion have been examined in the laboratory setting during various athletic movements including running, single leg squat, and landing from a jump. Kinematic differences during the SEBT anterior (ANT) reach between those with ACL-R and a control group have been demonstrated, including increased hip adduction and decreased hip/knee flexion. Despite the differences in kinematic profiles, Delahunt et al. found no significant quantifiable reach differences between these two groups. These findings highlight the importance of observation of movement patterns during rehabilitation in the presence of clinically acceptable quantitative SEBT reach performance. While the previous studies are useful for appreciating movement deficiencies, clinical application of laboratory-based research is often challenging. Rehabilitation professionals rarely have access to the sophisticated instrumentation and software required for three-dimensional biomechanical movement analysis, thus creating the need for visual assessment tools to evaluate dynamic postural control in an accessible and financially attainable manner.

Clinical scoring criteria have been developed to qualify other functional tasks including the tuck jump assessment, lateral step down test, and single leg squat test with clinically acceptable levels of reliability. Movement quality of these functional tasks were assessed based on the presence or degree of aberrant movement at the trunk, pelvis, hips, and knees. These aberrant movement patterns, in part are consistent with those associated with lower extremity injury from a previous investigation.

The SEBT has proven valuable as an instrument for predicting lower extremity injury and for pre-participation athlete screening. Although previous SEBT protocols do not suggest the need for qualitative analysis, the SEBT provides a platform to observe movement quality, which may guide future intervention and assist with the decision-making process of when to allow an athlete to return to competition. No prior studies have investigated movement quality observed in a clinical setting during the SEBT or determined if a relationship exists between movement quality and quantitative values on the SEBT. The purposes of this study were to (a) rate movement quality as observed during performance of the SEBT ANT reach, (b) determine if a relationship exists between movement quality and quantifiable outcomes of the SEBT, and (c) develop reliable scoring criteria to qualitatively describe movement during the SEBT. The authors’ hypothesis was that those individuals with more observable movement faults as defined by the predetermined scoring criteria would more likely be determined to be at risk on the SEBT, and that visual assessment of the knee would be the most reliable between raters.
METHODS

Subjects
Healthy subjects were recruited from a university population as a sample of convenience. A power analysis revealed that 100 subjects were needed to complete testing in order to attain the study’s objectives based on the proportion of subjects at-risk from previous studies. To be included in this study, subjects were required to be between the ages 18 and 35 years old. Subjects were excluded from participation if they reported (a) previous low back, hip/pelvis, knee, ankle, or foot surgery within the past year; (b) injury to the lower extremities or lower back in the previous six months; (c) lower extremity amputation; (d) currently undergoing treatment for inner ear, sinus, head cold, or upper respiratory infection; (e) known balance impairment due to neurological disorder, vestibular disorder, medication use, or other; (f) concussion within the previous three months; or (g) pregnancy. Compensation was not provided to the subjects for their participation. Prior to participation, each subject read and signed an informed consent form approved by the Institutional Review Boards of the University of Wisconsin – La Crosse and Gundersen Health System. Presence of pain during testing was not a specific objective of the current study, as the study population was limited to healthy, non-injured subjects.

Procedures
Two examiners performed data collection for this study during 2013-2014. Both examiners were sports physical therapy residents with similar levels of physical therapy clinical experience. Data collection took place in a university classroom setting. Initial data collected for each subject included sex, age, height (cm), body mass (kg), limb dominance (defined as the foot used to kick a soccer ball), and self-reported activity level using the Tegner Activity Level Scale. Prior to data collection, the examiners met to clarify procedures of the tests to be performed. Examiners performed pilot testing on five healthy subjects and made final modifications to the testing procedures.

Lower Limb Length
Limb length measurements were attained as described in a previous study. Measurements were performed with the subjects supine on a treatment table. Subject position was standardized by having the participant lie supine with bilateral hips and knees flexed to approximately 45°. The participant performed a bridge maneuver and slowly lowered the pelvis to the treatment table. The examiner passively straightened the lower limbs and provided a gentle distraction force. Limb length was measured in centimeters using a cloth tape measure from the inferior aspect of the anterior superior iliac spine (ASIS) of the pelvis to the ipsilateral distal medial malleolus.

Star Excursion Balance Test Protocol
The SEBT testing protocol was adapted from a previous study. Participants viewed an instructional video detailing procedures and demonstration of the SEBT prior to testing. During this video, the participant was educated on what constituted an unsuccessful trial. The trial was considered unsuccessful if the subject (a) lost balance or failed to maintain unilateral stance, (b) shifted weight onto the reach foot when touching the measuring tape, (c) failed to perform a controlled return of the reach foot to the starting position prior to reaching another direction, (d) did not maintain heel contact between the stance limb and floor, (e) did not maintain hands on the pelvis, (f) moved or lifted the stance foot, or (g) failed to touch the measuring tape. If the trial was deemed unsuccessful, it was discarded and repeated until a successful trial was performed.

The SEBT was performed in three reach directions as described previously. Three tape measures labeled in 0.5 cm increments were secured to the floor. One tape measure was oriented to the apex, which was defined as the ANT reach direction. Two additional tape measures were anchored at 135° to the apex, which were defined as the posteromedial (PM) and posterolateral (PL) reach directions. The stance foot starting position was defined as the area immediately adjacent to the stance limb in a non-weight-bearing position. Participants placed their hands on their iliac crests to standardize starting position while standing barefoot. Participants were required to tightly tuck in their shirts into their waistband, which was aligned to be level with their ASIS. A strip of white athletic tape was used to accent the ASIS landmarks. Shorts
were fit to allow for visualization of knee position. One-inch red stickers were placed over each tibial tuberosity for improved visualization. Reliability of the examiners collecting SEBT performance data was not established for the present study; however, previous investigations have demonstrated high intratester and intertester reliability during the SEBT with recommendations for completion of practice trials to account for learning effects.\(^1,2\)

Four practice trials were performed in all directions on each limb prior to administration of the test.\(^37\) Participants were given verbal feedback if they were performing the test incorrectly. No additional instructions were given regarding movement strategies or posture. Participants were given a two-minute rest period prior to formal testing. Formal testing included three test trials for each lower extremity for each of the ANT, PM, and PL reach directions. Each test trial was named and recorded according to stance limb and reach direction with the standardized testing order applied as follows: right ANT, left ANT, right PM, left PM, right PL, and left PL reach directions. The sum of the greatest reach distance for each of the three directions was divided by three times limb length and multiplied by 100 to calculate composite (COMP) reach distance for each leg.\(^9\)

A test trial failure was determined if a successful attempt was not established within six attempts for a particular direction. All test trials were observed and recorded by a principal examiner. The ANT reach test trial with the greatest reach distance was indicated on the examiner data sheet for retrospective rater viewing. Each ANT reach test trial was videotaped and transferred to DVD format for retrospective viewing. A video camera was positioned three meters in front of the subject to capture a full frontal plane view. Digital images were stored on a secure hard drive and transferred to DVDs for rater viewing.

**SEBT Movement Scoring and Clinician Raters**

From the quantitative scores attained from the SEBT, subjects were categorized into two groups: (a) those at-risk for future injury and (b) those not at-risk. Individuals were classified as at-risk if they met any of the following criteria: (a) a difference in reach distance between limbs in the ANT reach directions of greater than 4 cm,\(^9\) (b) COMP reach distance less than 94.0% of limb length for females,\(^9\) or (c) COMP reach distance less than 89.6% of limb length for males.\(^10\) All other subjects were categorized as not at-risk.

The ANT reach test trial with the greatest reach distance for each limb was independently viewed and scored by three physical therapist raters of varying clinical experience (18, 6, and 1.5 years) because this was the reach direction most predictive of lower extremity injury\(^9\) (Figure 1). Raters were blinded to SEBT quantitative values, as well as the determination of risk status. Three predetermined aberrant movement patterns (Table 1) were selected as a modification of the scoring criteria devised from previous investigations\(^30\) of the lateral step down test for the trunk, pelvis, and knee region. In addition, the altered kinematic profiles of hip and knee motion in an ACL-R population from a previous study were used to define the aberrant movement patterns.\(^8\) These movements were scored in a dichotomous manner as either present (1) or absent (0) throughout the ANT reach SEBT test trial for each limb. Total movement score was defined as the sum of movement faults for each respective limb, ranging from
0 to 3. Clinician raters were instructed to limit each trial to two real-time viewings, starting with the first subject. Raters received formal training on the scoring criteria prior to viewing the test trials.

**Statistical Methods**

The primary intent of this study was to examine the relationship between movement quality as determined by an experienced physical therapist and quantifiable SEBT outcomes. The degree to which rater assessments are able to predict risk status derived from the SEBT was assessed across the three raters for each side of the body (left vs right) and for the three body regions (trunk, pelvis, and knee) of interest, for a total of six comparisons. Calculations used the Cochran-Mantel-Haenszel test and resulting odds ratios, and homogeneity of the odds ratios was assessed via the Breslow-Day test. Interrater agreement for categorical responses was assessed via Cohen kappa with modifications for more than two raters, while agreement for ordinal responses was assessed via Kendall coefficient of concordance ($W$). Both calculations used the MAGREE macro. Groups were compared using Pearson $\chi^2$ tests for categorical data and the Wilcoxon rank sum tests for ordinal data. All calculations were performed with SAS/STAT 9.3 (Cary, NC), and a p-value of less than 0.05 was considered significant for all comparisons.

**RESULTS**

**Participants**

One hundred seven subjects volunteered for this study, seven of whom were excluded due to recent history of injury to the lower extremities or low back (n=4), sinus or upper respiratory infection (n=2), and recent history of concussion (n=1). One hundred subjects completed the testing protocol and were included in data analysis (Table 2). None of the subjects reported experiencing any personal harm during testing. Subjects were not significantly different in age, body mass index (BMI), or Tegner activity level with respect to SEBT risk classification. Of the subjects included in data analysis, females were significantly more likely than males to be classified as at-risk on at least one limb, per COMP risk criteria (Table 3).

**Rater Agreement**

In general, rater agreement with respect to the presence or absence of movement faults in the trunk and pelvis regions was poor to moderate, with kappa values ranging from 0.18 to 0.43 (Table 4). Agreement in knee assessment was consistently better when compared with that of the other regions ($\kappa=0.5-0.6$). Rater agreement on the total number of movement faults noted for each side of a subject was fair to moderate, with better agreement on the right side ($W=0.732$) than on the left ($W=0.644$).

<table>
<thead>
<tr>
<th>Table 1. Movement Scoring Criteria</th>
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</thead>
<tbody>
<tr>
<td><strong>Body region</strong></td>
</tr>
<tr>
<td>Trunk</td>
</tr>
<tr>
<td>Pelvis</td>
</tr>
<tr>
<td>Knee</td>
</tr>
<tr>
<td><em>Scored independently for each lower extremity throughout the anterior reach</em></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2. Subject Demographics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Characteristic</strong></td>
</tr>
<tr>
<td>Age, mean y ± SD</td>
</tr>
<tr>
<td>BMI, mean kg/m² ± SD</td>
</tr>
<tr>
<td>Sex</td>
</tr>
<tr>
<td>Limb dominance</td>
</tr>
<tr>
<td>SD= standard deviation; BMI= body mass index.</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3. Participant Classification of Risk</th>
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<tbody>
<tr>
<td><strong>Participant classification</strong></td>
</tr>
<tr>
<td>COMP or ANT reach at-risk</td>
</tr>
<tr>
<td>COMP and ANT reach at-risk</td>
</tr>
<tr>
<td>COMP reach at-risk</td>
</tr>
<tr>
<td>ANT reach at-risk</td>
</tr>
<tr>
<td>COMP=composite; ANT=anterior.</td>
</tr>
</tbody>
</table>
Rater Prediction of Risk
Collectively, rater finding of aberrant movement patterns was not predictive of an at-risk performance on the SEBT (Appendix 1). The only significant association between collective rater assessment and the COMP reach was a negative association between aberrant trunk movement patterns and the results of the SEBT on both the left and right sides; however interrater agreement in these regions was poor. With the exception of the left pelvic region, homogeneity of the odds ratios via the Breslow-Day test was acceptable. Additionally, subjects deemed at risk tended to have fewer movement faults per rater assessment (Appendix 2).

Examined individually, the sensitivity of rater assessment to detect at-risk performance per the SEBT was poor and varied significantly between raters and across body regions (Table 5). All three raters displayed moderately strong specificity in knee assessment—generally around 70%; however, specificity was notably lower and displayed larger variation between raters for the pelvis and trunk. When two or more raters agreed, collective rater knee specificity was acceptable for knee assessment (Appendix 3).

**DISCUSSION**

Movement Quality and SEBT Outcome
Contrary to the authors' initial hypothesis, those who were deemed at risk on COMP reach tended to display fewer movement faults per rater assessment of total movement score. This inverse movement fault to COMP at-risk relationship may be due to protective compensations. The subject may be able to maintain adequate control only within a certain range of their “cone of stability.”38 The cone of stability is a mapping within the central nervous system that is used to maintain equilibrium during a movement or task.38 The cone of stability may get distorted in the presence of impairments in proprioception, balance, or neuromuscular control.38 The authors hypothesize that subjects displaying fewer movement faults while still being at risk per SEBT scoring criteria may be unable or unwilling to move toward the limits of their cone of stability, therefore decreasing the use of aberrant movement patterns. It stands to reason that there would be an increase

Table 4. Interrater Agreement for Movement Assessment

<table>
<thead>
<tr>
<th>Body region</th>
<th>Kappa</th>
<th>% Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>Trunk</td>
<td>0.21</td>
<td>0.18</td>
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<tr>
<td>Pelvis</td>
<td>0.43</td>
<td>0.36</td>
</tr>
<tr>
<td>Knee</td>
<td>0.60</td>
<td>0.50</td>
</tr>
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</table>

Table 5. Individual Rater Sensitivity, Specificity, Negative Predictive Values, and Positive Predictive Values for SEBT At-Risk Performance

<table>
<thead>
<tr>
<th>Rater</th>
<th>Side</th>
<th>Body region</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>NPV</th>
<th>PPV</th>
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</thead>
<tbody>
<tr>
<td>1</td>
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<td>Trunk</td>
<td>0.804</td>
<td>0.023</td>
<td>0.083</td>
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<tr>
<td></td>
<td></td>
<td>Pelvis</td>
<td>0.518</td>
<td>0.477</td>
<td>0.438</td>
<td>0.558</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Knee</td>
<td>0.393</td>
<td>0.591</td>
<td>0.433</td>
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<tr>
<td></td>
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<td>0.813</td>
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<td>Pelvis</td>
<td>0.531</td>
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<td>0.423</td>
<td>0.708</td>
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<td></td>
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<td>0.297</td>
<td>0.75</td>
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<td>0.679</td>
</tr>
<tr>
<td>2</td>
<td>Left</td>
<td>Trunk</td>
<td>0.25</td>
<td>0.568</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Pelvis</td>
<td>0.125</td>
<td>0.591</td>
<td>0.347</td>
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<td>0.232</td>
<td>0.727</td>
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</tr>
<tr>
<td></td>
<td>Right</td>
<td>Trunk</td>
<td>0.313</td>
<td>0.556</td>
<td>0.313</td>
<td>0.556</td>
</tr>
<tr>
<td></td>
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<td>Pelvis</td>
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<td>0.611</td>
<td>0.355</td>
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<tr>
<td></td>
<td></td>
<td>Knee</td>
<td>0.141</td>
<td>0.778</td>
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<td>0.523</td>
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<tr>
<td>3</td>
<td>Left</td>
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<td>0.518</td>
<td>0.159</td>
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<td>0.439</td>
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<tr>
<td></td>
<td></td>
<td>Pelvis</td>
<td>0.321</td>
<td>0.591</td>
<td>0.406</td>
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<tr>
<td></td>
<td></td>
<td>Knee</td>
<td>0.25</td>
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<td>0.462</td>
<td>0.636</td>
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<td>Trunk</td>
<td>0.547</td>
<td>0.111</td>
<td>0.121</td>
<td>0.522</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pelvis</td>
<td>0.5</td>
<td>0.528</td>
<td>0.373</td>
<td>0.653</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Knee</td>
<td>0.156</td>
<td>0.778</td>
<td>0.341</td>
<td>0.556</td>
</tr>
</tbody>
</table>

NPV = negative predictive value; PPV = positive predictive value.
in aberrant movement patterns if the participant reached further toward the limits of their cone of stability. Further investigation is needed to identify whether a clinical relationship exists between movement strategy and SEBT performance.

Rater assessment of aberrant movement with respect to SEBT outcome varied according to each body segment. Lower extremity dynamic postural control is often depicted as a kinematic chain of interworking parts to complete a movement task. It has been demonstrated that aberrant movement of the lower extremity is often characterized by abnormal trunk position, poor pelvis and poor knee control rather than an isolated movement fault at a single location.39 When performing the SEBT, aberrant movement patterns may differ according to a limitation in a specific aspect of the movement. For example, an athlete with a limitation in dorsiflexion range of motion may adopt movement strategies vastly different from those displayed by an athlete with decreased proprioception—and such strategies may be specific to the impairment of the individual. Mobility limitations may alter the movement pattern of the athlete, as ANT reach distance has been shown to be influenced by ankle dorsiflexion range of motion.40,41 In addition, increased hip strength (i.e. greater proximal stability) has been positively correlated with SEBT performance.42,43 These various constructs of movement may influence movement quality or strategy according to the limitation placed on the athlete.

The SEBT has demonstrated the ability to predict injury risk by assessing both ANT and COMP reach performance.9,10 Clinical observation of SEBT movement quality occurred only in the ANT reach direction from a frontal plane perspective, limiting the generalizability of the findings for those with COMP risk outcome. In developing movement scoring criteria, the authors felt it was difficult to define reliable aberrant movement patterns in the PM and PL reach directions. Additionally, the SEBT reach is a three-dimensional task, which may complicate clinical observation of movement from a single-plane perspective. The addition of a sagittal plane perspective may have provided further insight into ANT reach movement assessment including relative knee and hip flexion angles. Ideally, movement quality assessment for the ANT reach direction would have been compared with ANT reach outcome; however, the current sample was too small to perform this analysis. Future research may identify movement scoring criteria in all reach directions in order to establish a better comparison with ANT and COMP risk.

Rater Agreement

Confirming the initial hypothesis, interrater reliability of movement assessment for the knee region was the highest of the three body regions. Rater agreement for knee assessment may have been greater due to improved visualization of the tibial tuberosity relative to the foot in the frontal plane. In contrast, contralateral pelvic drop and trunk lean/rotation may be too subtle to visually assess in a reliable fashion without specific anatomical landmarks to score the movement utilizing a single plane video perspective. Overall, agreement for total movement score between raters was fair to moderate, which was similar to that reported for previous investigations of the lateral step down test.30,32 Examiner reliability for collecting SEBT performance data was not established in the present study, as high intratester and intertester reliability during the SEBT has been demonstrated in previous investigations.1,2

Participants

The percentage of participants in the current study who were found to be at risk per COMP reach criteria was higher than that reported in previous studies.9,10 One study found a similar risk stratification for both males and females.9 Contrary to that finding, in the current study there was a significantly greater number of at-risk females as compared to males. Athlete gender is only one of the many intrinsic risk factors for lower extremity injury.12 Increased injury risk among female athletes may be partially attributed to neuromuscular control differences between men and women.44,45 While the difference between genders exists, dynamic postural control can be improved with an appropriate training program for female athletes.11 SEBT performance is dependent on age, sex, sport, and athletic ability.9,10,46 Previous studies reported on injury risk in high school athletes9 and collegiate football players,10 while the current study investigated active, college-aged individuals, with a majority of the subjects classified as recreational athletes. Differences in the total volume of at-risk subjects
may be explained in part by the differences in study population. Utilization of current risk stratifications as a screening tool or for guidance in return to sport decision making may not be as appropriate if applied to a recreational athletic population. Normative SEBT data and injury risk stratifications have yet to be established in individuals similar to those included in the current study. Further prospective investigation is warranted to establish normative data and risk stratification across various populations to expand the clinical utility of the SEBT as a screening tool.

Limitations
The results of the current study are generalizable to a healthy, college-aged population involved in recreational and competitive athletics. Limitations did not prevent attainment of the study objectives; however, generalizability of this single-center study was limited in a number of ways. Movement analysis using the SEBT was performed in healthy subjects, making clinical application to those with injuries a challenge. Subjects were not followed prospectively to determine incidence of lower extremity injury. Secondly, application of risk classification from previous investigations was limited due to inconsistencies between testing protocols as well as differences in performance between the SEBT and Y Balance Test. Applications of and clinical utility of the SEBT requires further investigation in order to develop guidelines for appropriate use in the rehabilitation setting.

Conclusion
Clinical observation of knee movement during performance of the ANT reach of the SEBT demonstrated acceptable interrater reliability and moderately strong specificity to detect at-risk SEBT outcome. Observation of trunk and pelvis movement demonstrated poor to moderate interrater reliability. Total movement score across all body regions demonstrated fair to moderate agreement between raters. Subjects who were at risk tended to have fewer movement faults.

Aberrant movement of the knee during the SEBT ANT reach appears to be the most reliable, and demonstrated the highest specificity for SEBT at-risk outcome when compared to the trunk and pelvis as identified by clinician raters. Future research should investigate the need for a qualitative assessment of the SEBT.

REFERENCES


38. Horak FB. Postural orientation and equilibrium: what do we need to know about neural control of


### Appendix 1. Odds Ratios for Rater Prediction of Risk

<table>
<thead>
<tr>
<th>Body region</th>
<th>Odds Ratio for prediction of Composite Risk only [95% CI]</th>
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### Appendix 2. Total Movement Score and SEBT Outcome

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### Appendix 3. Rater consensus (2 or more raters agree)

Sensitivity, Specificity, Negative Predictive Values (NPV), and Positive Predictive Values (PPV) for SEBT At-Risk Performance

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ABSTRACT

Background: Treatment of patellofemoral pain syndrome (PFPS) has been extensively studied in physical therapy literature. Patients with PFPS demonstrate quadriceps and hip musculature weakness, altered lower extremity (LE) kinematics, and decreased LE flexibility. Psychosocial factors have also been identified as an important factor in patients with PFPS. The authors hypothesize that an ordered approach addressing each of these impairments sequentially will result in greater improvement in PFPS symptoms. The purpose of this pilot study was to assess the feasibility of performing a randomized trial and to determine the sample size necessary to examine the validity of this hypothesis.

Methods: Patients received a sequential treatment approach using a PFPS treatment algorithm (PFPS Algorithm) designed by the authors. Patients were evaluated assessing psychosocial factors, flexibility, LE kinematics, and LE strength. Impairments that were found in the evaluation were addressed sequentially over the episode of care. Patients were prescribed therapy two times per week for six weeks. Pain, Anterior Knee Pain Scale (AKPS), and Global Rating of Change (GROC) were measured at evaluation and discharge.

Results: Thirty consecutive patients with PFPS who were referred to physical therapy were enrolled in the pilot study. All phases of the feasibility study including recruitment, treatment protocols and data collection were effectively carried out. One hundred percent of patients treated with the PFPS algorithm who completed the prescribed treatment had a clinically significant improvement in the AKPS and GROC. A floor effect was noted with NPRS with 38% of patients unable to achieve clinically significant improvement.

Conclusions: With minor changes to the protocol and outcome measures used, a full randomized trial is feasible and merited. Steps must be taken to reduce the high drop-out rate among both groups.

Keywords: Patellofemoral pain, knee pain, physical therapy.

Level of Evidence: 1b
INTRODUCTION

Patellofemoral pain syndrome (PFPS) accounts for 25 to 40% of knee pain in young and active individuals.1-3 PFPS is described as anterior knee pain around the patella which is aggravated by activity, particularly activities that increase patellofemoral forces such as squatting, ascending or descending stairs, running, and jumping.4,5 It is common in adolescents and physically active adults.6 Females are more likely to experience PFPS than males.7 PFPS is a multifactorial condition with no clear etiology and is considered a syndrome and not a diagnosis. Dye8 has described PFPS as one of the most difficult orthopedic conditions to manage.

Multiple theories exist regarding a cause for PFPS pain. A primary theory for the cause of PFPS is abnormal patellar tracking which results in excessive patellofemoral joint compressive forces.9,10 Many factors contributing to abnormal patellar tracking have been suggested including; hip and quadriceps weakness, delayed or diminished activation of vastus medialis obliquus, increased Q-angle, altered lower extremity mechanics and decreased lower extremity flexibility. Due to the number of suggested contributory factors to PFPS pain, a vast amount of interventions exist and are frequently used by clinicians. Although, physical therapy interventions have been shown to be effective over sham interventions, many individuals will have recurrent or chronic pain. Ninety-six percent of patients report having problems four years following their diagnosis of PFPS.11 A possible reason for the continued pain is that PFPS is a multifactorial condition and the treatments may not address all of the contributing factors in each individual.

If all of the contributing factors for the patient's PFPS are identified, addressing all of these factors at once may not be the best approach. Performing hip strengthening prior to quadriceps strengthening results in decreased levels of pain with exercise.12 Individuals with reduced flexibility are more likely to have impaired lower extremity mechanics.13 Performing traditional lower extremity strengthening exercises when there is impaired lower extremity mechanics results in increased patellofemoral joint contact forces.14

In an attempt to better treat individuals with PFPS, classification systems to subgroup patients with PFPS have been proposed, but their effectiveness has not been evaluated.15-20 An important clinical question with classification systems is what to do when a patient does not nicely fit into one subgroup. If a patient does not meet or meets the criteria for multiple subgroups, how is the patient treated? No evidence exists on the relative frequency with which patients with PFPS fall into each of these proposed subgroups and whether these subgroups are mutually exclusive.

The clinical classification systems reported in literature only address physical impairments. Psychosocial factors have also been identified as important when treating patients with PFPS. In a study by Piva et al21 fear avoidance beliefs were the strongest predictor of outcomes for function and pain. Mental health status on the Medical Outcomes Short Form-36 is correlated with severity of patellofemoral symptoms in athletes.22 The results of these studies highlight the necessity of addressing psychosocial factors when treating PFPS.

Therefore, the authors have designed a new classification system (PFPS algorithm) for subgrouping patients based on the patient's clinical presentation. There are four subgroups in the new PFPS algorithm: Fear-Avoidance, Flexibility, Functional Malalignment, and Strengthening with function progression. The criteria and intervention of each subgroup is addressed sequentially over the episode of care. This classification system aims to address problems encountered if individuals meet the criteria for multiple subgroups. There is also a psychosocial component to address the needs of individuals with activity avoidance. The PFPS algorithm is goal-based, where meeting the criteria to pass through each subgroup is the focus of the treatment. Clinicians can provide whichever physical therapy intervention that allows an individual patient to meet the criteria of each subgroup. Interventions used in the PFPS algorithm are based on best available evidence, clinician's experience, and the patient's individual response to the intervention.

The authors hypothesize that an ordered approach addressing each of these impairments sequentially will result in greater improvements in function and pain than traditional treatment for PFPS symptoms.
The clinical application of the new PFPS algorithm and the ability to recruit patients with PFPS has not been assessed. Therefore, it was decided to complete a pilot study to assess the feasibility of successfully implementing and completing a randomized controlled trial (RCT) to examine the validity of this hypothesis. The purpose of this pilot study was to determine the feasibility of (1) Appropriately delivering the PFPS algorithm in the clinic setting; (2) Recruiting enough patients to perform a full RCT; (3) Outcome measures appropriate to assess the outcomes of a full RCT.

METHODS
The design of this study is a randomized controlled pilot trial using consecutive patients referred to two physical therapy clinics. Patients with peripatellar pain who were referred to Nationwide Children’s Hospital’s physical therapy clinics for treatment were considered for participation. The institutional review board approved this study prior to recruitment and data collection. All patients and guardians provided written informed consent prior to participation. This study was registered at ClinicalTrials.gov (Identifier number NCT01767246).

ELIGIBILITY CRITERIA
Patients were eligible for this study if a clinical diagnosis of PFPS was made by the evaluating therapist. Patients were considered to have a clinical diagnosis of PFPS if the inclusion and exclusion criteria were met. (Table 1) Patients were also excluded from the study if they were unable to follow directions, had a history of activity limiting illness, were pregnant or nursing, or stated they were unable to attend follow-up appointments.

<table>
<thead>
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<th>Inclusion Criteria</th>
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<td>Patient at least 12 years of age</td>
<td>Tenderness to palpation of the patellar tendon, inferior pole of the patella, or tibial tubercle as the primary complaint.</td>
</tr>
<tr>
<td>Peripatellar knee pain</td>
<td>Other diagnosis of the knee including: patellar tendinitis, iliotibial band syndrome, Osgood-Schlatter’s disease, Sinding-Larsen’s Johansson’s disease, fracture, or ligamentous injuries.</td>
</tr>
<tr>
<td></td>
<td>Prior knee surgery</td>
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<tr>
<td></td>
<td>History of patellar subluxation or dislocation</td>
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</table>

Table 1. Inclusion and exclusion criteria

INTERVENTIONS
Patients received physical therapy treatments two times per week for six weeks for a total of 12 treatments. Patients were also given a home exercise program that was to be performed daily.

PFPS Algorithm
Patients were evaluated using the PFPS algorithm assessing psychosocial factors, flexibility, LE kinematics and LE functional strength sequentially. (Figure 1) Patients were placed in treatment subgroups based upon the impairments that were found in the evaluation and impairments were addressed in this ordered approach over the episode of care.

The first impairment assessed in the PFPS algorithm was fear avoidance. Patients were placed in this treatment subgroup if they scored ≥ 15 on the Fear Avoidance Belief questionnaire-physical activity subscale (FABQ-PA) modified for the knee. Patients who scored ≥ 15 on the FABQ-PA were treated using a combination of education and a graded exercise program that incorporated gradual exposure to stimuli. Fear avoidance education de-emphasized anatomic findings and encouraged the patients to take an active role in their recovery. Therapeutic exercise focused on functional gains with exercise instead of pain.

Lower extremity flexibility was the second impairment assessed in the PFPS algorithm. Patients were considered to have flexibility deficits if they demonstrated tightness in one of the three primary muscles. Flexibility testing of the primary muscles was assessed for quadriceps (Figure 2) gastrocnemius (Figure 3) and soleus (Figure 4 and Figure 5). If a patient demonstrated tightness of three of the four
secondary muscles the patient was also considered to have flexibility deficits. Secondary muscle flexibility tests were performed using the Thomas test for hip flexors, Ober’s test for the iliotibial band, straight leg raise test for hamstring flexibility, and adductor flexibility in supine. Treatment in this subgroup focused on stretching of the tight muscles. Low-level quadriceps and hip strengthening was also incorporated during this treatment phase as stretching alone has been found to be non-effective.

The functional malalignment subgroup addressed neuromuscular control of the core and lower extremities during dynamic movement. Functional malalignment was assessed using the lateral step down test (Figure 6) and the single leg squat test (Figure 7). Scoring for both tests were based on criteria previously reported in literature. A score of moderate or poor placed the participant in the functional malalignment subgroup. Treatment in this subgroup focused on LE mechanics during dynamic activity and strengthening of muscles necessary to maintain proper alignment. The focus of LE mechanics was individualized to match the functional activity in which each patient participated.

The strengthening subgroup, the final classification in the PFPS algorithm, focused on high level strengthening of the lower quarter with emphasis on the quadriceps, hip abductors and external rotators and functional progression back to full activity. Strength was assessed by performing the single leg hop for distance, the triple leg hop for distance, the cross-over hop for distance as described by Myer et al and the timed step down test (Figure 8). All tests were assessed using the Limb Symmetry Index. A score of less than 90% placed the participant in this group.

**OUTCOME MEASURES**

The outcome measures utilized in this study included the Numeric Pain Rating Scale (NPRS), the
Anterior Knee Pain Scale (AKPS) and the Global rating of Change Scale (GROC). Each were collected and measured at evaluation and discharge. Additionally, the Fear Avoidance Belief Questionnaire...
The physical activity subscale (FABQ-PA) was collected at initial evaluation.

Pain was measured using the NPRS. The use of the Numerical Pain Rating Scale for assessing pain has been validated for use in this patient population and has been found to have a minimal detectable change of two points.25 The NPRS is an 11-point pain-rating scale ranging from 0 (no pain) to 10 (worst imaginable pain) to assess current pain intensity and the best and worst level of pain during the last 24 hours.26 An average of the three ratings was used.

The AKPS and GROC have been utilized in clinical outcome studies and recommended for use with PFPS patients. The AKPS is a self-reported 13-item questionnaire with discrete categories related to various levels of current knee function. Categories within each item are weighted, and responses are summed to provide an overall score of 0-100, with 100 representing no disability. The AKPS is found to be valid.

Figure 6. Lateral Step Down Test
The lateral step down test was performed by having the patient stand on a 20 cm (8 inch) step and perform a squat to approximately 60 degrees. The patient was instructed to keep the trunk straight, hands on waist and bend the knee on the tested side until the heel on the opposite side touches the small step or floor. The patient was instructed to keep the knee of the tested leg over the second toe and lightly touch the heel to the floor and then return to the starting position. Patients repeated the step down 5 times.

Figure 7. Single Leg Squat Test
The single leg squat test is performed by having the patient squat while standing on one leg. The patient was instructed to keep the knee of the tested leg over the second toe and squat until he/she is no longer able to see their toes then return to the starting position. The patient repeated the squat 5 times.

Figure 8. Timed step down test
Unilateral test performed from a platform 20 cm (8 inch) high. The patient stepped forward and down toward the floor. The lowered limb only brushes the floor with the heel and then returns to starting position. This is counted as one repetition. The number of repetitions the patient performs in 30 seconds is recorded. Both limbs are tested.
and reliable in patients from 12-50 years of age presenting with anterior knee pain with a test-retest reliability of .95. A change of 10 points represents the minimal clinical difference. The GROC is a 15-point Likert type scale (-7 to +7). A score of 0 represents no change from initial injury, +7 represents a great deal better, and -7 represents a great deal worse. A score of +/- 3 represents a minimal clinical difference.

Patient's fear of pain and beliefs about avoiding activity was measured with the FABQ-PA subscale. Higher FABQ physical activity subscale scores have been associated with greater activity limitation in the adolescent population. The FABQ also includes a work subscale component that is scored separately from the FABQ-PA. The work subscale was not included because many patients with PFPS are younger and may not participate in regular work activity and the score would likely not be valid.

RELIABILITY TESTING
To assess the inter-rater reliability of the subgrouping of the PFPS algorithm, two therapists evaluated each patient on the same day during their course of treatment. Each therapist separately tested and subgrouped the patient into the treatment group they deemed appropriate. Therapists were blinded to the evaluation and decision of the other therapist.

RECRUITMENT AND SAMPLE SIZE
No external strategies were used to recruit patients into this study. A sample of males and females 12 years and older were to be drawn from two pediatric outpatient orthopedic physical therapy clinics over the course of one year. There was no predetermined sample size; assessing the ability to recruit an appropriate number of eligible patients was an objective of this pilot study.

DATA ANALYSIS
Descriptive statistics and other exploratory analysis were calculated using SPSS version 21.0 (SPSS Inc. Chicago, IL). Inter-rater reliability was calculated using Cohen’s Kappa statistic.

RESULTS
Patients were recruited from two outpatient pediatric physical therapy facilities. Eligible patients were recruited from February 2013 to February 2014. Thirty patients met the inclusion criteria and agreed to participate in the study, with 21 patients completing the study protocol (Figure 9).

SAFETY
No serious adverse reactions were noted with treatment using the PFPS algorithm. There were a few reports of mild adverse reactions consistent with side effects of exercise and manual therapy, such as soreness and mild knee pain with exercise. No patient dropped out of the pilot study due to the side effects of the treatment.

ELIGIBLE PATIENTS
During the one-year period of recruitment for the pilot study 157 patients were referred to participating physical therapists with knee pain. 19.1% of those patients met the inclusion criteria to participate in the pilot study. No eligible patient refused to participate in the pilot study. On average, 2.5 patients per month were recruited to participate in the pilot study. Thirty percent of the patients who consented to participate in the pilot study did not complete the prescribed treatment.

APPROPRIATE DELIVERY OF INTERVENTIONS
A subjective review of the treatment notes indicated that the treating therapist adhered to the PFPS algorithm...
in 100% of patients. Cohen's κ was run to determine if there was agreement between therapists' subgrouping of patients using the PFPS algorithm. Fifteen total patients were assessed by two therapists each. Therapists agreed on the treatment subgroup in 14 patients. There was very good inter-rater reliability with a Kappa Score of 0.90 (95% CI, 0.72 to 1.00), p < .0005.

BASELINE DEMOGRAPHICS (TABLE 2)
There were no outliers found in baseline variables, as assessed by inspection of a boxplot. The AKPS, NPRS and GROC scores were normally distributed at each time point, as assessed by Shapiro-Wilk's test (p > .05).

AKPS CHANGE
Clinically significant change with the PFPS algorithm treatment was noted at the six-week follow-up, with a mean change of 18.00 (SD 6.27) on the AKPS. One hundred percent of patients treated with the PFPS algorithm who completed the prescribed treatment had a clinically significant improvement in their AKPS score.

NPRS CHANGE
No clinically significant changes were noted at the six-week follow up for pain. The mean change in NPRS for the PFPS algorithm group was -1.84 (SD 1.04). Only 33% of patients had a clinically significant improvement in NPRS. Thirty-eight percent of patients had an initial NPRS of <2 making a clinically significant improvement impossible in these patients.

GLOBAL RATING OF CHANGE
Clinically significant change on the GROC was noted at the six-week follow-up with the PFPS algorithm, with a mean change of 5.30 (SD 1.42). One hundred percent of patients treated with the PFPS algorithm experienced a clinically significant improvement at the six-week follow-up on the GROC.

SAMPLE SIZE CALCULATION FOR FULL TRIAL
Calculations regarding sample size were conducted using the formula recommended by Noordjiz et al\(^3\) for randomized controlled trials. The AKPS was considered the primary outcome. The calculations were made using alpha = .05, beta = .20, a minimal clinically important difference between groups of 10, and a within-group standard deviation (SD) of 12.4. These parameters were based on the findings of previous research.\(^2,3\) Twenty-five subjects per group will be required to adequately achieve statistical power for the primary outcome of AKPS during a full study.

DISCUSSION
The cause of PFPS is not clearly understood. Current evidence suggests that it is multifactorial, with patients presenting with quadriceps and hip musculature weakness, altered lower extremity kinematics, decreased flexibility and psychosocial stressors. This pilot study suggests that a full RCT using an ordered treatment approach addressing soft tissue tightness, altered lower extremity kinematics, neuromuscular deficits and psychosocial stressors in a sequential manor may be feasible provided using the following modifications to the protocol.

The PFPS algorithm was properly implemented into physical therapy clinics. The pilot study used five sports and orthopedic physical therapists from 2 physical therapy clinics. Patients were treated, whenever possible, by the evaluating therapist for the duration of the treatment. After receiving training in the PFPS algorithm all therapists were able to evaluate and treat patients in a consistent manner. There was a high level of inter-rater reliability, 90%, when placing patients into their subgrouping categories indicating a high level of agreement between therapists for progressing patients through the PFPS algorithm. Clinicians reported the PFPS algorithm was easily performed in a normal clinic setting and no deviations from treatment protocol were noted.

Recruitment of patients for a full RCT was deemed feasible with patients referred to these physical

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<td>Pain</td>
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*Data are means (SD) or numbers (%); FABQ= Fear Avoidance Behavior Questionnaire.*
therapy clinics if the number of physical therapists participating in the full RCT is increased. Currently, only 20% of the clinics’ physical therapist participated in recruitment. Recruitment rates can be increased even further by training additional physical therapists in the implementation of the research protocol. Training can be completed without disrupting patient care. The sample size necessary for a full RCT is 25 patients in each group with the comparator group being typical PFPS treatment. Accounting for dropout rates, a total number of 58 patients are necessary, based on a goal of limiting the dropout rate to 15%. By increasing the number of participating therapists, recruitment of the necessary patients could be completed in less than one year. No barriers were found to patients agreeing to participate in the study, with all eligible patients and parents consenting to participate.

The PFPS algorithm was deemed clinically effective for treating patients with PFPS. Clinically significant changes in function were noted in 100% of patients treated with the PFPS algorithm, with a mean change of 18.00 (SD 6.27) on the AKPS. Clinically significant change was also noted on the GROC in the PFPS algorithm group, with a mean change of 5.30 (SD 1.42). No clinically significant changes were noted at the six-week follow up for pain. A floor effect was noted in a third of all patients, suggesting that an average of the three NPRS scores is not the best measure to assess clinically significant change in this population.

Two of the three outcome measures used in this pilot study were appropriate for assessing outcomes in a full RCT. The AKPS appears appropriate to measure function in patients with PFPS. The AKPS has been widely used and has been demonstrated to be valid and reliable for patients with PFPS. The AKPS scale is appropriate for patients with PFPS 12 years of age and older and is the gold standard for measuring function in those with PFPS. No patient was unable to demonstrate clinically significant improvement on the AKPS due to a ceiling effect. The GROC also appears to be an appropriate measure to assess the patient’s perceived level of overall improvement. This measure with knee injuries and a cut score of +3 was found to indicate important change.29 The NPRS using an average of three scores (highest, lowest, and current pain) was deemed inappropriate for use in a full RCT. A floor effect was noted in a significant number of patients who had an initial NPRS of <2, making clinically significant improvement impossible. Using the highest level of pain or pain during activity on the NPRS might be more appropriate than an average measure of pain.

**LIMITATIONS AND FUTURE TRIAL CONSIDERATIONS**

The high dropout rate was a significant limitation of the current pilot study. This dropout rate would be unacceptable in a full RCT, introducing bias into the results. Two patients did not complete their assigned intervention for unavoidable reasons (concussion and unrelated surgery), but the dropout rate in the remaining patients should be decreased. To decrease the dropout rate changes have been proposed. First, the authors will attempt to secure a small source of funds to compensate research study patients for their time in order to help reduce the financial burden of participating and to motivate patients to participate for the entire study duration. Second, the expectations for participation in the study will be more clearly defined on the consent form, so all eligible patients have a clear understanding of what is needed to complete their prescribed course of treatment.

Another limitation of this pilot study was that the treating therapist and patient were not blinded. With the constant evaluation necessary to progress patients through the PFPS algorithm, blinding would be impractical, but there is the possibility of treatment bias with this approach. All outcomes were based on patient self-report measures reducing this limitation. Treatment duration and contact with the physical therapist will be the same for both groups in the full RCT.

Minor changes to the PFPS algorithm have been proposed to improve the ability of patients to advance from one subgroup to the next. The need was most evident when patients were attempting to advance out of the flexibility subgroup to the functional malalignment subgroup. Due to the high cutoff score for standing DF motion required to advance, it was difficult for many patients to meet this requirement. This may be resolved by decreasing the cutoff
criteria for standing dorsiflexion from 50 degrees to 48 degrees. Although this decrease is small, many patients peaked at 48 or 49 degrees of WB DF and had difficulty achieving 50 degrees. The change in cutoff score is based on using the upper limit of the 95% CI for patients that would fail the lateral step down criteria compared with using the lower limit of patients who would have passed.

Although clinically meaningful results were found with the PFPS algorithm, this pilot study was performed to guide future trial design. The results of this pilot study should not be generalized to patients until a fully powered RCT can be performed.

CONCLUSION
The primary aims of this pilot study were met. The therapists and clinic personnel successfully worked together to carry out all treatments required to conduct a future full scale RCT. The ordered treatment approach used in the PFPS algorithm, addressing soft tissue tightness, altered lower extremity kinematics, neuromuscular deficits and psychosocial factors in a sequential manner, resulted in clinically significant improvements in AKPS and GROC scores. With minor changes to the protocol and outcome measures used, a full RCT assessing the effectiveness of the PFPS algorithm is feasible.

REFERENCES


ABSTRACT

Background: Squats and lunges are commonly prescribed rehabilitation exercises used to improve performance across a wide spectrum of patient populations. However, biomechanical studies have mainly examined young, normal weight populations performing these exercises at a difficulty level potentially too challenging for obese individuals. Understanding how obesity and different levels of difficulty affect lower extremity biomechanics could help to inform rehabilitation approaches used for obese individuals.

Purpose: The purpose of this study was to analyze and compare the lower extremity kinematics and kinetics in obese and normal weight females during performance of progressively more difficult squat and lunge exercises.

Study Design: Cross-sectional study design

Methods: Ten obese females (mean age, 37.4 years; BMI 39.2 ± 3.7 kg/m²) and ten normal-weight, age-matched female controls (38.1 years, BMI < 23 kg/m²) volunteered for the study. Each group performed two exercises, each in three different iterations: squatting at three standardized knee angles (60°, 70°, and 80°) and lunging at three standardized distances (1.0, 1.1, and 1.2 times tibial length). Three dimensional motion analysis using infrared markers and force plates was used to calculate range of motion as well as hip, knee, ankle and support moments (normalized for body weight). A repeated measures ANOVA model was used to determine between and within group differences.

Results: Support moments were higher in obese females for squat 70° (p=0.03) and 80° (p=0.01). Ankle extensor moments were higher in obese females for squat 80° (p=0.04). During lunge at all levels (1.0, 1.1, and 1.2), hip extensor moments were higher in obese subjects (p=0.004, 0.003, and 0.007 respectively). Within group, the support moments were significantly higher during squat 80° than squat 60° (p=0.01) in obese females. A non-linear relationship was found between hip moments and BMI during squat 60°, 70°, and 80°.

Conclusion: During two commonly prescribed rehabilitation exercises (squat and lunge), there were significantly greater support moments in obese individuals compared to normal controls. The non-linear associations between kinetic and anthropometric measures make the assessment of how best to approach exercise in obese individuals challenging.

Level of evidence: Level 3

Key words: Biomechanics, lunge, obesity, physical therapy, squat
INTRODUCTION

Squat and lunge exercises are common activities that have become an integral part of lower-extremity strengthening and postoperative rehabilitation programs. They are universally used with patients across the spectrum of age and body mass index (BMI). The closed-chain, multi-joint nature of these exercises is considered part of the basic rehabilitation strategy that has implications for improved performance in functional activities and gait. Gradation of these exercises not only challenges the torque requirements across the lower limb joints, but also challenges standing balance.

Previous research on squat and lunge exercises has primarily focused on electromyographic analysis to study muscle recruitment and strengthening with few studies focusing on the biomechanics. Biomechanical analyses have demonstrated varying lower limb kinetic demands during rehabilitation of ACL reconstructive patients when performing the squat exercise. During the lunge exercise, the influence of forward trunk position on lower limb kinetics, specifically hip and knee joint moments, has been documented. While these exercises are used clinically across the age spectrum, most studies have been conducted on younger, normal-weight populations. Thus, the influence of obesity on performance has not been documented.

Although no studies of obese individuals performing these two activities were found, previous studies underscore the potential for adiposity to influence activity performance. An increase in biomechanical stresses, as quantified by joint moments, has been reported during standing forward reaching tasks in obese subjects. Gilley el al suggested that increased moments were likely due to biomechanically disadvantageous postures used by obese individuals, rather than their increased body mass. Underlying these postural deviations are reductions in joint range of motion, which may cause modification in the movement strategy, with potential implications for increases in associated biomechanical stresses. When performing sit to stand activities, lower hip and higher knee extensor moments were seen in obese subjects as compared to normal-weight subjects, attributable to limited trunk flexion. It seems possible that obese individuals may use similar postural modifications and movement strategies when performing rehabilitation exercises, such as the squat and lunge, resulting in altered biomechanical joint stresses, contributing to joint pain and discomfort that is commonly experienced by this population.

Despite the potential for biomechanical performance differences in obese individuals, namely increased joint stress and limited range of motion, when compared to normal-weight individuals, there is no published data demonstrating that clinicians make different recommendations when prescribing exercises for obese individuals. Taking the biomechanical stresses and strategies into consideration during common exercises may improve the rehabilitation approaches used for obese individuals; specifically adult women, who are particularly at risk for developing musculoskeletal disorders like knee osteoarthritis. The purpose of this study was to analyze the biomechanics of obese and normal-weight females, as measured by hip, knee, and ankle moments, during squat and lunge exercises. It was hypothesized that restricted joint mobility in obese females would be associated with decreased hip and increased knee joint moments as compared to normal-weight females, and that these differences would be more evident as the level of difficulty of squat and lunge increased.

METHODS

Participants

Ten obese females (BMI > 30 kg/m²), age 37.4 ± 3.7 years, BMI 39.2 ± 3.7 kg/m² and ten normal-weight (BMI < 23 kg/m²), age-matched, female controls, age 38.1 ± 4.5 years, BMI 21.6 ± 2.3 kg/m², volunteered for the study. All subjects provided informed consent prior to participation in the study.

Procedures

The study protocol was approved by the Institutional Review Board of the University of Iowa, Iowa City, IA. The subjects came to the laboratory for a single session, when all necessary data was collected. Height, weight, waist circumference, hip circumference and tibial length were recorded prior to testing. Waist circumference was measured at the level of the right iliac crest and hip circumference was mea-
sured at the widest part of the hip with a Gulick II tape measure (Country Technology Inc., Gays Mills, WI). Triads of infrared emitting diodes (IREDs) were placed on the pelvis and trunk, and bilaterally on the thighs, legs, and feet. Markers were affixed to the lateral aspect of the foot, to the shaft of the tibia, and to the lateral aspect of the thigh. Femoral epicondyle motion was tracked by two markers mounted on a custom femoral tracking device. Pelvic and trunk marker triads were attached to 5 cm extensions with base plates affixed over the sacrum and lower cervical vertebrae (Figure 1).

A link-based model was generated for tracking each segment. Anatomical landmarks were digitized, relative to segment local coordinate systems, with the subject standing in a neutral position, to create an anatomical model. Segment principal axes were defined by digitizing the following bony landmarks: Pelvis: anterior and posterior superior iliac spines; Trunk: C-7 and L-1 vertebrae and glenohumeral joints; Thigh: lateral condyle, medial condyle and functional hip joint center; Shank: lateral condyle, medial condyle and malleoli; Foot: posterior heel, 5th metatarsal head, and second toe. The functional method was used to estimate the hip joint center. The reliability of digitizing the anterior superior iliac spine (ASIS) was verified on six obese and seven normal-weight adult subjects by re-digitizing the ASIS landmarks at the end of the digitizing process. The respective ICC for the X, Y, Z locations for obese/normal-weight subjects was 0.93/0.99; 0.92/0.86; and 0.99/0.99.

Kinematic data were collected using an Optotrak motion analysis system (Model 3020, Northern Digital Inc., Waterloo, Ontario, Canada) operating at 60 Hz. Kinematic data were filtered at 6 Hz, using a zero phase lag, fourth-order, Butterworth low pass filter. Kinetic data were obtained using a Kistler force plate (Kistler Instruments, Inc., Amherst, NY). The force plate data were sampled at 300 Hz, and were filtered at 6 Hz. Visual 3D software (C-Motion Inc. Kingston, Ontario) was used to perform link-segment calculations.

Testing sessions included two trials of each difficulty level of the squat and lunge. The squat protocol consisted of squatting down, feet shoulder width apart, with right foot on the force plate and held for three seconds at three different knee angles: 60°, 70°, and 80° of knee flexion (full knee extension being 0°) (Figure 1). Real time feedback, showing a target line and a line representing the right knee angle in real-time, was used to achieve the desired knee angle. The forward lunge was held for three seconds, with feet shoulder width apart and positioned on the force plates, at three different distances between heel and toe: 1.0, 1.1, 1.2 times subject's tibial length (Figure 1).
Data Analysis
Visual 3D software (C-Motion) was used for processing kinematics and inverse kinetics. The moments were normalized to body weight. Lower limb range of motion at the hip, knee, and ankle, and trunk segment flexion angles, were determined from link-segment analysis. Mean values, while holding each position for three seconds, were calculated for lower limb joint range of motion, net joint moments and support moment (summation of the lower limb ankle, knee and hip extensor moments). The mean of two trials, for both activities, was used for further analysis.

Statistical Analysis
Descriptive statistics in the form of means and standard deviation were estimated. A repeated measures ANOVA model (3x2; joint moments by level of difficulty) with group (obese versus normal-weight) as a between subject factor was fitted to investigate differences in hip, knee, ankle and support moments across three levels of difficulty for the squat and for the lunge. A group-by-level of difficulty interaction effect was included in the model. Pearson correlation coefficients were estimated to quantify the strength of the linear association between moments and range of motion. Regression analysis was performed to define relationships between BMI or other anthropometric measures and moments. SPSS 21.0 was used for analysis with p-value < 0.05 considered significant. All results are presented as means ± standard deviation.

RESULTS
All 20 subjects (10 obese and 10 normal-weight) recruited for the study completed the protocol. No differences were seen in hip, knee, or ankle range of motion between obese and normal-weight subjects during the squat or lunge (Table 1); specifically, no differences were seen for knee range of motion for squat 60°, squat 70°, or squat 80° indicating that both groups performed the squat to a similar depth. Also, no significant differences were seen in trunk flexion angle between the two groups for the squat or lunge (Table 1).

For the squat, normalized hip and knee extensor moments in obese subjects were not different than normal-weight subjects at any degree of squat angle. Ankle extensor moments were higher in obese subjects for squat 80° (p = 0.04) (Table 2). The support moments were higher in obese subjects, as compared to the normal-weight subjects, for squat 70° (p = 0.03) and squat 80° (p = 0.01), but not different for squat 60° (p = 0.07). Within groups, the support moments between squat 80° were greater than squat 60° in obese subjects (p = 0.01) (Figure 2).

For the lunge, hip extensor moments were higher in obese subjects at all three levels: 1.0, 1.1, and 1.2 leg length (Figure 3). Knee and ankle extensor moments were not different between obese and normal-weight groups at any difficulty level of lunging (Table 2). Support moments showed an overall group effect between obese and normal-weight subjects (p = 0.01).

Pearson correlation coefficients calculated between extensor moments (hip and knee) and range of motion were stronger in obese subjects as compared to normal-weight subjects. For lunge, the correlation coefficients were significant in obese subjects and higher in magnitude as compared to normal-

Table 1. Hip, knee, ankle and trunk range of motion for different levels of squat and lunge exercises in obese and normal weight subjects.

<table>
<thead>
<tr>
<th></th>
<th>Hip</th>
<th>Knee</th>
<th>Ankle</th>
<th>Trunk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obese</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Squat 60°</td>
<td>64.7</td>
<td>62.3</td>
<td>59.6</td>
<td>57.5</td>
</tr>
<tr>
<td>(19.2)</td>
<td>(22.5)</td>
<td>(7.9)</td>
<td>(6.7)</td>
<td>(5.8)</td>
</tr>
<tr>
<td>Squat 70°</td>
<td>75.6</td>
<td>71.4</td>
<td>68.4</td>
<td>66.2</td>
</tr>
<tr>
<td>(23.2)</td>
<td>(25.0)</td>
<td>(8.5)</td>
<td>(7.5)</td>
<td>(6.3)</td>
</tr>
<tr>
<td>Squat 80°</td>
<td>85.0</td>
<td>82.4</td>
<td>78.3</td>
<td>75.3</td>
</tr>
<tr>
<td>(24.2)</td>
<td>(24.9)</td>
<td>(9.3)</td>
<td>(7.5)</td>
<td>(5.7)</td>
</tr>
<tr>
<td>Lunge 1.0</td>
<td>98.4</td>
<td>89.1</td>
<td>83.6</td>
<td>86.7</td>
</tr>
<tr>
<td>(12.2)</td>
<td>(20.9)</td>
<td>(12.7)</td>
<td>(9.3)</td>
<td>(6.9)</td>
</tr>
<tr>
<td>Lunge 1.1</td>
<td>102.4</td>
<td>91.4</td>
<td>88.0</td>
<td>85.9</td>
</tr>
<tr>
<td>(12.8)</td>
<td>(19.9)</td>
<td>(11.5)</td>
<td>(11.1)</td>
<td>(7.4)</td>
</tr>
<tr>
<td>Lunge 1.2</td>
<td>102.4</td>
<td>92.7</td>
<td>88.3</td>
<td>86.5</td>
</tr>
<tr>
<td>(14.3)</td>
<td>(17.7)</td>
<td>(13.4)</td>
<td>(10.0)</td>
<td>(8.9)</td>
</tr>
</tbody>
</table>

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There was no linear association between BMI, waist circumference, or waist to hip ratio and joint moments for the squat or lunge at different difficulty levels. However, when the data were split into obese and normal-weight subjects based on BMI, obese subjects showed a stronger relationship ($R^2=0.46$) as compared to normal-weight subjects ($R^2=0.26$) for hip extensor moments for squat 60°. Also, there was a non-linear relationship between peak hip extensor moment and BMI for squat 60° ($R^2=0.14$). A moderate relationship was seen for ankle ($R^2=0.03$) for squat 60°, but no relationship was seen for the knee during the same squat ($R^2=0.03$).

**DISCUSSION**

The purpose of this study was to analyze the biomechanics during the squat and lunge of obese and normal-weight females, as measured by hip, knee and ankle moments. For the squat, the normalized support moments were higher in obese subjects when performing the two deeper squats (squat 70° and 80°). The lunge exercise showed group differences in normalized hip moments and support moments for all difficulty levels (lunge 1.0, 1.1 and 1.2). Joint range of motion was not different between obese and normal weight subjects for either activity; however, the association between range of motion and extensor moments was greater in the obese women when compared to controls. The results suggest that obese individuals may experience higher biomechanical loads than normal-weight individuals while performing basic rehabilitation exercises at varying

**Table 2.** *Hip, knee, ankle extensor and support moments for different levels of squat and lunge exercises in obese and normal weight subjects.*

<table>
<thead>
<tr>
<th></th>
<th>Hip Moment</th>
<th>Knee Moment</th>
<th>Ankle Moment</th>
<th>Support Moment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Obese</td>
<td>Normal</td>
<td>Obese</td>
<td>Normal</td>
</tr>
<tr>
<td>Squat 60°</td>
<td>0.22 (0.24)</td>
<td>0.12 (0.17)</td>
<td>0.67 (0.10)</td>
<td>0.59 (0.22)</td>
</tr>
<tr>
<td>Squat 70°</td>
<td>0.29 (0.28)</td>
<td>0.17 (0.18)</td>
<td>0.73 (0.12)</td>
<td>0.66 (0.23)</td>
</tr>
<tr>
<td>Squat 80°</td>
<td>0.37 (0.30)</td>
<td>0.24 (0.18)</td>
<td>0.82 (0.12)</td>
<td>0.75 (0.26)</td>
</tr>
<tr>
<td>Lunge 1.0</td>
<td>1.32* (0.27)</td>
<td>0.96* (0.39)</td>
<td>0.53 (0.15)</td>
<td>0.64 (0.30)</td>
</tr>
<tr>
<td>Lunge 1.1</td>
<td>1.41* (0.28)</td>
<td>1.07* (0.38)</td>
<td>0.53 (0.16)</td>
<td>0.56 (0.29)</td>
</tr>
<tr>
<td>Lunge 1.2</td>
<td>1.48* (0.32)</td>
<td>1.14* (0.39)</td>
<td>0.50 (0.22)</td>
<td>0.52 (0.24)</td>
</tr>
</tbody>
</table>

*Significant difference between two groups ($p<0.05$)
across the three lower limb joints points to the possibility of higher generalized joint stress in obese subjects during squatting.

Analysis of the lunge exercise data showed an increase in the hip moments for the obese group and no differences in the knee and ankle moments. These results were contrary to the hypothesis that hip moments would decrease due to limits in trunk flexion, as has been reported in previous work on sit to stand activities in obese compared to normal-weight individuals. However, in the current study there was no difference in trunk flexion between the obese group and the normal-weight group, so the increase in hip moments in the obese group could be due to mass distribution, i.e. bringing the center of mass forward. A recent study of the effect of adding an external load on the biomechanics in young, normal-weight individuals during lunge exercises, showed an increase in hip extensor moments with little change in the knee moments. It could be argued that the external weight simulated the excess adipose tissue in obese individuals, causing a similar increase in hip moments. This association was reinforced with the findings of a moderate relationship (R²=0.22) between hip moments and waist to hip ratios in the obese group, implying that relatively greater abdominal adiposity may be associated with greater hip moments.

Although there were no significant differences in range of motion between the obese and normal-weight groups for either activity, stronger correlations between moments and range of motion were seen in the obese group. These higher correlations, in combination with higher support moments, might point to subtle restrictions in movement capability, which gave the obese group less flexibility in how they accomplished the squat and lunge exercises. Evidence supporting this is also seen in the standard deviations for the trunk and hip ROM (Table 1) which were consistently less in the obese population.

Additionally, a non-linear relationship between hip moments and BMI was found (Figure 4). A non-linear relationship indicates that an increase in BMI was not proportionally related to an increase in hip moments. Instead, this relationship followed a polynomial curve, suggesting the possibility of a ceiling effect in subjects with higher BMIs. A similar
The present study had certain limitations. First, it only examined the squat to a depth of 80 degrees of knee flexion, while some previous studies used a greater range of motion for squatting. The chosen range of motion for squatting resulted from pilot work where obese females were reluctant to perform deeper squats and due to safety concerns. Similar concerns limited the farthest lunge to 1.2 times the tibial length. These concerns were likely not an issue for the normal weight subjects who likely could have completed more challenging versions of these activities. Additionally, while subjects were instructed in the task and allowed to practice, their performance was not uniform. The strategies employed by subjects to reach the final position of the squat and the lunge exercise might have influenced their static posture and thus, the moments. Finally, the sample size may have limited the ability to find statistically significant differences in some of the outcome measures. As no previous studies on squat and lunge have been conducted in obese individuals, a sample size calculation was not feasible before the start of the study. However, post-hoc power analysis based on the means from the current study showed good power (0.85) for lunge exercise, but low power (0.40) for squat trials.

CONCLUSION
Clinicians commonly progress rehabilitation protocols by increasing the difficulty of the exercise: by either increasing the depth of the squat or increasing the distance between feet during the lunge. The current study identified significant increases in lower limb kinetics in obese individuals during these squat and lunge exercises. These stressors may have consequences for obese individuals where there is also an increased likelihood of joint pathology; therefore, using the same exercise progressions for both obese and normal-weight individuals may not be optimal. In addition, the sensitivity of joint moments to changes in ROM is greater for obese individuals, which would suggest that clinicians might need to be more sensitive to subtleties in performance. Finally, the non-linear associations that have been uncovered between anthropometric measures and kinetic measures make the assessment of how to best approach exercise in this population even more challenging. This results of this study suggest the need to consider obesity as a factor in exercise prescription and demonstrates the complexity of factors that interact to influence kinetic measures.

REFERENCES
THE VALIDITY AND RELIABILITY OF A NEW INSTRUMENTED DEVICE FOR MEASURING ANKLE DORSIFLEXION RANGE OF MOTION

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Pedro Gargallo, MsC
Jessica García-Redondo, MsC
Juan Carlos Colado, PhD
Pedro J. Marin, PhD, PT

ABSTRACT

Purpose/Background: A restriction in ankle dorsiflexion range of motion (ROM) has been linked to several clinical manifestations such as metatarsalgia, heel pain, nerve entrapment, ankle joint equinus, patellar and ankle injuries. The purpose of the present study was to examine the validity and reliability of the Leg Motion system for measuring ankle dorsiflexion ROM.

Study Design: Descriptive repeated-measures study.

Methods: Twenty-six healthy male university students were recruited to test the reliability of the Leg Motion system, which is a portable tool used for assessment of ankle dorsiflexion during the weight-bearing lunge test. The participants were tested twice separated by two weeks and measurements were performed at the same time of the day by the same single rater. To test the validity of the Leg Motion system, other maximal ankle dorsiflexion ROM assessments (goniometer, inclinometer and measuring tape) were measured in a single session (i.e., the first test session) during the weight-bearing lunge position using a standard goniometer, a digital inclinometer and a measuring tape measure with the ability to measure to the nearest 0.1 cm.

Results: Paired t-tests showed the absence of significant differences between right and left limb measurements of dorsiflexion in all tests. Mean values ± standard deviations were as follows: Leg Motion test (left 11.6cm ± 3.9; right 11.9cm ± 4.0), tape measure (left 11.6cm ± 4.0; right 11.8cm ± 4.2), goniometer (left 40.6º ± 5.2; right 40.6º ± 5.2), and digital inclinometer (left 40.0º ± 5.8; right 39.9º ± 5.6). The Leg Motion composite values (i.e., average of the two legs) showed a significant (p<0.05) positive correlation with the tape measure (r = 0.99), with the goniometer (r = 0.66), and with the digital inclinometer (r = 0.72).

Conclusions: The results of the present study provide evidence to support the use of the Leg Motion system as a valid, portable, and easy to use alternative to the weight-bearing lunge test to assess ankle dorsiflexion ROM in healthy participants.

Level of evidence: 2b.

Key words: Ankle dorsiflexion, goniometer, inclinometer, weight-bearing lunge

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INTRODUCTION

A restriction of ankle dorsiflexion range of motion (ROM) has been linked to several clinical manifestations such as metatarsalgia, heel pain, nerve entrapment, ankle joint equinus, patellar and ankle injuries. Restricted ankle dorsiflexion may also lead to abnormal lower extremity biomechanics during closed chain strengthening exercises. For example, reduced ankle dorsiflexion during a squat results in increased knee valgus and medial knee displacement, decreased quadriceps activation, and increased soleus activation. In addition, daily activities such as walking, descending stairs, and kneeling require 10° of ankle dorsiflexion ROM while other actions such as sprinting and running require 20° to 30°. In recent years, several methods of assessment have been studied and performed in order to measure ankle dorsiflexion ROM. For instance, the weight-bearing lunge test, the goniometer, and the digital inclinometer are usually used for this purpose.

Konor and colleagues and Bennell and colleagues found that the tape measure using the distance-to-wall technique during the weight-bearing lunge test has higher intraclass correlation coefficient (ICC) values (ICC = 0.99) than the standard goniometer and digital inclinometer. However, there is no universal agreement regarding which of these methods of measurement is most preferred. Weight-bearing measures are considered to be more related to daily activities such as walking, running, or stair ambulation than values obtained from other non-weight-bearing tests. Moreover, weight-bearing dorsiflexion ROM is associated with dynamic balance, showing a significant, fair correlation with the anterior reach distance in the star excursion balance test among healthy adults (τ = 0.53) and in individuals with chronic ankle instability (τ = 0.41).

Regardless of the higher reliability showed by the weight-bearing lunge test in comparison with other measures, there are some potential variations that occur during testing that need to be controlled. For instance, variations in the subtalar and foot position, the visual reference for the knee or the maintenance of the foot alignment during the performance of the test may change dorsiflexion results and are the main limitations with regard to the standardization of this test.

Cejudo and colleagues described a new simplified version of the weight-bearing lunge test to assess ankle dorsiflexion ROM and reported high relative reliability scores (ICC > 0.9). However, no study provides an alternative, validated weight-bearing test associated with the most common ankle dorsiflexion ROM tests. An alternative option to perform a weight-bearing evaluation that provides a standardized assessment is the Leg Motion system, a new portable device designed to assess ankle dorsiflexion ROM, in a similar manner to the weight-bearing lunge test assessment. For instance, during the weight-bearing lunge test subjects have adjust their foot toward or away from the wall, whereas during the assessment with the Leg Motion system, the metal stick is progressed away from knee, allowing for improved standardization during testing, since the foot is always in the same position and any possible movement that may influence in the outcome is reduced. Moreover, the Leg Motion system is a more efficient method for testing compared to the traditional wall lunge test as each measurement can be noted by simply moving the stick away from the knee as ankle dorsiflexion increases rather that measuring multiple attempts where participants have to stop and modify foot and body posture each time. The Leg Motion system also provides greater standardization due to the measurement scale where the foot is placed in comparison with the measuring tape that is used during the typical weight-bearing lunge test. Additionally, the Leg Motion system is a portable device that allows for easier completion of the test in virtually any location, without the need for walls or a particular floor where a measuring tape needs to be placed or where the normal weight-bearing lunge test has limitations (e.g., a grass surface). To the authors’ knowledge, this is the first device that enables the performance of a weight-bearing test in such standardized conditions and no study has been conducted to evaluate the comparison of the measurements achieved via this novel device with other typical ankle dorsiflexion ROM measures. The purpose of the present study was to examine the validity and the reliability of the Leg Motion system for measuring ankle dorsiflexion ROM. The authors’ hypothesized that Leg Motion system would provide both valid and reliable measurements of ankle dorsiflexion ROM.
METHODS

Subjects
Twenty-six healthy male university students (age 22.5±2.1 years, height 165.9±48.7 cm, weight 77.2±8.4 kg, body mass index 14.54±2.87 kg/m²) volunteered to take part in this study. Participants were required to be free from lower extremity injury for at least six months prior to testing, and have no prior history of hip, knee, or ankle surgery.

All participants signed an institutional informed consent form before starting the protocol and the study was approved by the institutions’ review boards. All procedures described in this section comply with the requirements listed in the 1975 Declaration of Helsinki and its 2008 amendment.

Protocol
Height (IP0955, Invicta Plastics Limited, Leicester, England), body mass, and body fat (Tanita model BF-350, Tokyo, Japan) were obtained according to the protocol used in the study conducted by Garcia-Masso and colleagues.14

In order to test the reliability of the Leg Motion system, the participants were tested in two different sessions at the same time of day, with a separation of two weeks between sessions. Both assessments were conducted by the same researcher according to the reliability protocol established by Ortega and colleagues.15 The researcher was a third year physiotherapy student with basic experience in the use of the goniometer and the inclinometer.

To test the validity of the Leg Motion system, the other maximal ankle dorsiflexion ROM was measured in a single session (i.e., the first test session) during the weight-bearing lunge position using a standard goniometer with 1° increments (Baseline, USA), a digital inclinometer with 1° increments (Baseline, USA) and a measuring tape with the ability to measure to the nearest 0.1 centimeter. The weight-bearing lunge test was performed with both limbs following the recommendations by Konor and colleagues.8 When the participant reached the maximal dorsiflexion ROM during the weight-bearing lunge test (defined as the maximum distance of the toe from the wall while maintaining contact between the wall and knee without lifting the heel),9 a digital inclinometer was placed at the tibial tuberosity and was used to measure the angle of the tibia relative to the ground.8 Likewise, a standard goniometer was aligned with the floor, and through the shaft of the fibula by visually bisecting the lateral malleolus and the fibular head.8,16

The Leg Motion system test was performed in accordance with the procedures for the performance of the weight-bearing lunge test. Subjects were in a standing position on Leg Motion system (Check your MOtion, Albacete, Spain) with the test foot on the measurement scale (Figure 1). While maintaining this position, subjects were instructed to perform a lunge in which the knee was flexed with the goal of making contact between the anterior knee and the metal stick. When subject were able to maintain heel and knee contact, the metal stick was progressed away from knee. Maximal dorsiflexion ROM during the Leg Motion system test was defined as the maximum distance of the toe from the metal stick while maintaining contact between the stick and knee for three seconds, without lifting the heel.

Figure 1. The Leg Motion System
All the measurements were completed with the participant barefoot; first performing all tests with one leg and then with the contralateral leg in a counterbalanced order. Three trials were allowed for each side, and the average value of the three trials was used for data analysis. A trial was discarded and repeated if a participant lifted their heel off the ground or did not follow the standards for performing the test.

**Data analysis**

Statistical analysis was carried out using SPSS version 17 (SPSS inc., Chicago, IL, USA). The level of significance was set at p < 0.05 for all statistical tests. Means and standard deviations were calculated for both limbs. Additionally, composite scores (i.e., average of the two legs) were calculated. Paired t-tests on the differences of scores obtained at test and retest sessions were used to ensure the absence of systematic bias.17

The ICC (3,1) was calculated to assess the relative between-session reliability, normalizing measurement error relative to the heterogeneity of the subjects.18 Criteria ranges for ICC reliability were as follows: <0.50, poor; 0.50 to 0.75, moderate; and >0.75, good.19 Standard error of measurement (SEM) [pooled standard deviation of all scores multiplied by the square root of 1-ICC] and 95% confidence intervals (CI) were computed to estimate the amount of error associated with the measurement. Moreover, minimal detectable difference (MDD) was analyzed (SEM*1.96*√2) in order to determine the minimum threshold of measurement to ensure that differences between measurements were real and outside the error range.18 A Pearson correlation analysis was carried out in order to evaluate the relationship between the Leg Motion system test and the other ankle dorsiflexion ROM measures.

**RESULTS**

Mean values ± standard deviations were as follows: Leg Motion system (left 11.6cm±3.9; right 11.9cm ± 4.0), tape measure (left 11.6 cm± 4.0; right 11.8 cm± 4.2), goniometer (left 40.6º± 5.2; right 40.6º± 5.2), and digital inclinometer (left 40.0º± 5.8; right 39.9º± 5.6) (Table 1). The Leg Motion composite values (i.e., average of the two legs) showed a significant (p<0.01) positive Pearson correlation with the tape measure, the goniometer and with the digital inclinometer. Correlation results are presented in Table 2. Paired t-test showed the absence of significant differences between limbs and between test and re-test values. Test re-test reliability results for the Leg Motion system was as follows: SEM ranged from 0.58cm to 0.80cm, MDD ranged from 1.60 cm to 2.23 cm and ICC values ranged from 0.96 to 0.98. Complete reliability results are represented in Table 3.

**DISCUSSION**

This is the first study to examine the validity of the Leg Motion system and report its test re-test reliability. The high correlation values obtained during the Leg Motion system test shows the validity of this device as an alternative to the weight-bearing lunge test, goniometer, and digital inclinometer for the measurement of the ankle dorsiflexion ROM. Specially, very high values were achieved when comparing the Leg Motion system test with the weight-bearing lunge test since both tests are very similar.

With regard to the reliability analysis, the authors' found highly reliable results on test re-test measures, since SEM values ranged from 0.58 cm to 0.80 cm, MDD ranged from 1.60 cm to 2.23 cm and ICC's ranged from 0.96 to 0.98. In accordance, other ankle dorsiflexion ROM measurements during weight-bearing positions have been shown to demonstrate high intra-rater reliability results using the digital inclinometer and the distance-to-wall measurements (ICC ranging from 0.97-0.98).9 Similarly, Konor and colleagues8 found good intra-rater reliabil-

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**Table 1. Results of Ankle Dorsiflexion Range of Motion Measurements**

<table>
<thead>
<tr>
<th>Measure Type</th>
<th>Left side</th>
<th>Right side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leg Motion System</td>
<td>11.6cm±3.9</td>
<td>11.9cm±4.0</td>
</tr>
<tr>
<td>Tape measure</td>
<td>11.6cm±4.0</td>
<td>11.8cm±4.2</td>
</tr>
<tr>
<td>Goniometer</td>
<td>40.6º±5.2</td>
<td>40.9º±5.3</td>
</tr>
<tr>
<td>Inclinometer</td>
<td>40.0º±5.8</td>
<td>39.9º±5.6</td>
</tr>
</tbody>
</table>
ity (ICC > 0.85) results for weight-bearing ankle dorsiflexion ROM measures when the measurements were performed by a novice rater utilizing a goniometer, inclinometer, or tape measure. However, these authors found that the reliability values for the digital inclinometer and the weight-bearing lunge test were higher than those using the goniometer. Good inter-rater reliability results using a digital inclinometer (ICC ranging from 0.77 to 0.88) were found when authors compared novice and experienced raters.\textsuperscript{16} While it is difficult to compare between reliability coefficients from different studies, the weight-bearing tests provide the same or higher ICC values when those are compared with other tests using the inclinometer or the goniometer.\textsuperscript{8}

The low measurement error found in the current study is in accordance with the SEM values provided by Konor and colleagues\textsuperscript{8} (intrarater SEM ranging from 0.4 cm from 0.6 cm) and Bennell and colleagues\textsuperscript{9} (intrarater SEM ranging from 0.5 cm from 0.6 cm) for measurements taken using the tape measure. Moreover, in the study conducted by Konor and colleagues,\textsuperscript{8} authors found MDD values that were similar to the current results (MDD ranging from 1.1 cm to 1.5 cm).

Since the Leg Motion system provides a standardized device in order to perform the weight-bearing lunge test under a controlled condition, the measurements during this test may vary slightly compared with the other distance-to-wall assessments. For example, during the Leg Motion test, participants progress their knee towards a metal stick instead of towards the wall, providing a visual target to maintain foot and knee alignment.

The results of this study are limited to the healthy participants that were studied, so the results may not be extrapolated to other injured populations. Another limitation of the study is the use of a non-

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
 & Leg Motion & Leg Motion & Leg Motion \\
 & Left Side & Right Side & Composite \\
\hline
Tape measure & & & \\
Left side & 0.98* & 0.89* & 0.96* \\
Right side & 0.91* & 0.98* & 0.97* \\
Composite & 0.96* & 0.96* & 0.99* \\
\hline
Goniometer & & & \\
Left side & 0.72* & 0.52* & 0.64* \\
Right side & 0.65* & 0.57* & 0.63* \\
Composite & 0.71* & 0.57* & 0.66* \\
\hline
Inclinometer & & & \\
Left side & 0.77* & 0.54* & 0.67* \\
Right side & 0.66* & 0.73* & 0.71* \\
Composite & 0.78* & 0.62* & 0.72* \\
\hline
\end{tabular}
\caption{Correlation coefficients between Leg Motion system test results and other ankle dorsiflexion range of motion measurements}
\end{table}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|}
\hline
 & Mean & SD & SEM & MDD & ICC (95\% CI) \\
\hline
Left Side & 12.37 & 3.82 & 0.58 & 1.60 & 0.98 (0.95; 0.99) \\
Right Side & 12.73 & 3.83 & 0.80 & 2.23 & 0.96 (0.90; 0.98) \\
Composite & 12.55 & 3.70 & 0.59 & 1.62 & 0.98 (0.95; 0.99) \\
\hline
\end{tabular}
\caption{Intrarater reliability for Leg Motion results}
\end{table}

Abbreviations. SD: standard deviation; SEM: standard error of measurement; MD: minimal difference; ICC: intraclass correlation coefficient values and 95\% CI: confidence intervals. Composite values = average of right and left sides.
randomized order when the tests were performed. However, since the main objective was to validate the Leg Motion test, the measurement of the ROM with the inclinometer and the goniometer needed to be performed during the weight-bearing lunge test, and the lack of randomized order likely had no effect. The use of a rater with basic experience could be a limitation, especially with regard to reliability testing. However, the authors found highly reliable results that are in similar to the previous literature demonstrating that a person with basic experience may perform the test with high reliability, adding to the feasibility and the practical application of the Leg Motion system.

CONCLUSIONS
The results of the present study provide evidence to support the use of the Leg Motion system as a valid, portable, and easy to use alternative to the weight-bearing lunge test to assess ankle dorsiflexion ROM in healthy participants. Moreover, the current findings demonstrate that a single rater with basic experience demonstrates highly reliable results during the assessment of dorsiflexion ROM using the Leg Motion system.

REFERENCES
ABSTRACT

Background: Increased flexibility is often desirable immediately prior to sports performance. Static stretching (SS) has historically been the main method for increasing joint range-of-motion (ROM) acutely. However, SS is associated with acute reductions in performance. Foam rolling (FR) is a form of self-myofascial release (SMR) that also increases joint ROM acutely but does not seem to reduce force production. However, FR has never previously been studied in resistance-trained athletes, in adolescents, or in individuals accustomed to SMR.

Objective: To compare the effects of SS and FR and a combination of both (FR+SS) of the plantarflexors on passive ankle dorsiflexion ROM in resistance-trained, adolescent athletes with at least six months of FR experience.

Methods: Eleven resistance-trained, adolescent athletes with at least six months of both resistance-training and FR experience were tested on three separate occasions in a randomized cross-over design. The subjects were assessed for passive ankle dorsiflexion ROM after a period of passive rest pre-intervention, immediately post-intervention and after 10, 15, and 20 minutes of passive rest. Following the pre-intervention test, the subjects randomly performed either SS, FR or FR+SS. SS and FR each comprised 3 sets of 30 seconds of the intervention with 10 seconds of inter-set rest. FR+SS comprised the protocol from the FR condition followed by the protocol from the SS condition in sequence.

Results: A significant effect of time was found for SS, FR and FR+SS. Post hoc testing revealed increases in ROM between baseline and post-intervention by 6.2% for SS (p < 0.05) and 9.1% for FR+SS (p < 0.05) but not for FR alone. Post hoc testing did not reveal any other significant differences between baseline and any other time point for any condition. A significant effect of condition was observed immediately post-intervention. Post hoc testing revealed that FR+SS was superior to FR (p < 0.05) for increasing ROM.

Conclusions: FR, SS and FR+SS all lead to acute increases in flexibility and FR+SS appears to have an additive effect in comparison with FR alone. All three interventions (FR, SS and FR+SS) have time courses that lasted less than 10 minutes.

Level of evidence: 2c

Key words: Ankle, dorsiflexion, flexibility, self-massage, stretching
INTRODUCTION
Increased flexibility, as defined by greater joint range-of-motion (ROM), is often desirable immediately prior to sports performance. Static stretching (SS) is commonly recommended for increasing flexibility acutely.¹ However, SS has been associated with acute reductions in performance in sporting movements,¹,² which are not desirable. Self-myofascial release (SMR) is an alternative modality that has also been reported to increase flexibility acutely.³,⁴,⁵,⁶ Unlike SS, increases in flexibility following from SMR appear to occur without concomitant reductions in force production.³,⁴,⁵,⁶,⁷,⁸ Additionally, with the growing popularity of SMR methods like foam rolling (FR), there is a pressing need for scientific investigation of their effects. SMR methods including FR and roller massage sticks have not only been shown to increase flexibility but also to reduce arterial stiffness, improve arterial function and improve vascular endothelial function⁹ and reduce soreness,⁶,¹⁰ which makes their use particularly interesting for both athletes and the general population.

Previous research has shown that SMR can increase flexibility acutely in untrained, adult subjects with no SMR experience.³,⁴,⁵,⁶ However, no previous study has reported on the effect of SMR on acute flexibility in subjects with experience of using SMR tools, nor on the effects of SMR on acute flexibility in adolescent subjects, in athletes, or in those with resistance-training experience. Experience with SMR tools has been suggested as a potentially important modifying factor for the acute effects of SMR on flexibility. Curran et al¹¹ proposed that individual technique, rather than physical dimensions, might be important for determining the ability to apply pressure to the underlying tissue. It was therefore suggested that subjects with experience of SMR may be better at applying pressure and thereby able to gain greater acute effects on flexibility from its use. Equally, it is possible that experience with SMR may instead lead to acclimatization to its effects and consequently any subsequent acute increases in flexibility might be smaller.

While many athletes may benefit from increased flexibility at certain joints for particular purposes, it has been reported that swimmers may specifically benefit from increased ankle flexibility¹²,¹³,¹⁴ and that this may improve performance. Therefore, methods to increase ankle flexibility in swimmers are of particular interest. Young et al¹⁵ performed a systematic review on interventions that are effective over long-term periods but no similar review exists for acute effects. Nevertheless, it has been reported that SS is effective for acute increases in ankle dorsiflexion ROM.¹,¹⁶,¹⁷ Additionally, Halperin et al³ also reported that SMR using a roller massager was able to induce acute increases in ankle dorsiflexion ROM. However, whether the acute effects of SMR and SS are additive in respect of either ankle dorsiflexion ROM or at any other joint has not been previously investigated. It is possible that performing both SMR and SS together may be superior to performing either modality alone for improving flexibility acutely. The only trial performed in which a combination of both SMR and SS was investigated did not explore passive ankle dorsiflexion ROM acutely. Rather, Mohr et al¹⁸ compared the long-term effects of FR, SS and a combination of FR and SS on passive hip flexion ROM. Mohr et al¹⁸ recruited 40 subjects with limited passive hip flexion ROM and randomly allocated them into either a control group or intervention groups who performed either SS, SMR or a combination for six sessions. A significant change in passive hip flexion ROM was found, regardless of treatment. In addition, the combined group displayed a significantly greater improvement than any of the other groups. These findings suggest that since SMR and SS demonstrated an additive effect over a long-term investigation, they may also be effective acutely, when compared with either SS or SMR alone.

How long acute improvements in flexibility following SMR last is unclear. Previous studies have shown that acute increases in flexibility persist for at least 10 minutes post-intervention.³,⁵,⁶ However, Jay et al⁶ found that there were no significant differences in flexibility at 30 minutes post-intervention between FR and a control. Thus, it appears that improvements in flexibility last from 10 to 30 minutes, the exact duration is unknown. How long acute improvements in flexibility following SS last has been subject to more investigation but is equally unclear on account of conflicting reports. DePino et al¹⁹ investigated knee extension ROM following a hamstring SS protocol at 1, 3, 6, 9, 15, and 30 minutes and found that there were no significant effects
beyond three minutes. Halperin et al. showed that ankle dorsiflexion ROM remained increased 10 minutes post-SS intervention. Ryan et al. reported that ankle dorsiflexion ROM returned to baseline levels at 10 minutes post-SS intervention, regardless of the duration of the plantarflexor SS protocol (2, 4 and 8 minutes, respectively). How long acute improvements in flexibility following from a combination of SMR and SS last is unknown. The findings of Mohr et al. suggest that since the two treatment modalities may be additive in increasing flexibility in a long-term trial they may also be additive regarding the duration of acute increases in flexibility in comparison with either SS or SMR alone.

Since FR has never previously been studied in relation to SS in adolescents, in resistance-trained athletes or in individuals accustomed to FR, the primary purpose of this trial was to compare the acute effects of FR and SS and a combination of both (FR+SS) of the plantarflexors on passive ankle dorsiflexion ROM in resistance-trained, adolescent athletes with at least six months of FR experience. On the basis of previous research suggesting an additive effect of SMR and SS over a short-term period, it was anticipated that FR+SS might be superior to FR and SS. The null hypothesis was therefore that there would be no difference between the interventions. Additionally, since the duration of effects of FR, SS and FR+SS are unclear, a secondary purpose of this trial was to compare the duration of any acute changes in flexibility in each condition over four time points post-intervention (immediately post-intervention and after 10, 15 and 20 minutes). Again, since there are indications that an additive effect of SS and FR might exist, it was anticipated that the duration of FR+SS might exceed that of SS and FR alone. The null hypothesis was that there would be no difference between the interventions.

**METHODS**

**Subjects**

Eleven adolescent, trained swimmers were recruited (5 females and 6 males, age: 15.3 ± 1.0 years, height: 172.3 ± 8.6 cm, weight: 64.5 ± 10.3 kg) who were participating in 16 hours of swimming training, three hours of resistance-training, and at least 30 minutes of FR per week, for the six months prior to the commencement of the trial. To be included in the trial, the subjects had to be free from any ankle-related or lower-limb injury, as this may have influenced the mobility of the ankle joint. Since all subjects had a minimum of six months of resistance-training experience, they can be classified as intermediate resistance-trained according to American College of Sports Medicine (ACSM) definitions. The parents of all subjects provided written consent prior to participation. The Ethical Commission of Faculty of Sport, University of Ljubljana, approved this study.

**Experimental approach**

A randomized within-subject design was used to explore the acute effects of SS, FR and a combination FR+SS, on passive ankle dorsiflexion ROM. The subjects used their dominant leg throughout the study, which was determined by reference to the leg that they would kick a ball with. Each subject visited the gym in which they were accustomed to exercising on three separate occasions at similar times in the day (between 4 – 5 pm) to avoid diurnal variations, with a minimum of 24 hours between each visit. On each visit, the subjects performed one of the three interventions (SS, FR, and FR+SS). The order of the three interventions was randomized for each subject. Randomization was performed by blinded selection of paper tokens by the subjects upon which a number was written. Upon arrival for the first visit, all subjects selected a piece of paper from a container. The number provided the order of conditions to be followed for that subject. The container was supplied with the same number of pieces of paper for each permutation of conditions. Each intervention was performed barefoot and no warm-up activity was performed beforehand. Each visit began with a baseline measurement of passive ankle dorsiflexion ROM, which served as a control, following the procedure used for later measurements, as outlined below, and as shown in Figure 4. Subjects then proceeded with one of the interventions (SS, FR, FR+SS). Immediately post-intervention, passive ankle dorsiflexion ROM was measured. In order to assess the time course of improvements in flexibility, further measurements of passive ankle dorsiflexion ROM were also taken at 10, 15 and 20 minutes post-intervention, respectively.
Static stretching comprised a single plantarflexor stretch performed for 3 sets of 30 seconds in duration with a 15-second rest between sets. To perform this stretch, the subjects stood with one leg on the edge of a bench, extended the knee and dorsiflexed, pointing their heel towards the ground. During the stretch, the subjects were allowed to lean on the wall for balance (Figure 1). The subjects were instructed to stretch to the point of discomfort but not to the point of pain. This stretching protocol was based on that outlined in a recent study performed in untrained subjects. However, it differed insofar as Halperin et al. instructed subjects to stretch the plantarflexors to a pain level on a scale of 7 out of 10. Foam rolling was also performed 3 sets of 30 seconds in duration with a 15-second rest between sets. In this way, the volume of work performed in the FR and SS conditions was equalized. The FR group used The Grid Foam Roller (Trigger Point Technologies, 5321 Industrial Oaks Blvd., Austin, Texas 78735, USA), which is composed of uniform cylinder with a hard, hollow inner core enclosed with a layer of ethylene vinyl acetate foam. This type of roller appears to produce more pressure on the soft tissue than traditional foam roller made out of polystyrene foam. Foam rolling was performed in a seated position with the legs extended and the feet relaxed as shown in Figure 2 and 3. One leg was crossed over the other to allow more pressure to be directed over the plantarflexor being treated. The subjects were instructed to use their arms to propel their body back and forward, from popliteal fossa to achilles tendon, in fluid
motions. They were also instructed to exert as much pressure on the foam roller as possible. Combination of foam rolling and static stretching consisted of the FR intervention directly followed by the SS intervention.

Measurements of passive ankle dorsiflexion ROM were taken by reference to a weight-bearing lunge test, as shown in Figure 4. It has been shown that this type of test has a high inter-rater and intrarater reliability. A measurement tape was placed on the floor perpendicular to the wall, in order to measure the linear distance between the big toe and the wall. Subjects stood on the tape with their big toe and heel. They were allowed to lean on the wall for better balance. Subjects were instructed to lunge their knee toward a wall in order to make contact with it. The foot was progressively moved away from a wall until the maximum ROM of the ankle was attained without heel lift. To control heel lift an elastic resistance band (Thera-Band, Hygienic Corporation, Akron, OH, USA) was placed under the subject’s heel as described by Halperin et al. The elastic resistance band was placed under tension by an experimenter. Where heel lift occurred, the elastic resistance band was pulled away and the results were declared invalid. Unlimited number of tries were allowed to attain the maximum passive ankle dorsiflexion ROM, as measured by reference to the linear distance between the big toe and the wall. Results from the test were rounded up to the nearest 0.5 cm.

STATISTICAL ANALYSIS

Normality of the data were assessed using the Shapiro-Wilk test and sphericity was investigated using Mauchly’s test. The results were analysed using SPSS (SPSS 17.0 for Windows Inc., Chicago, IL, USA). A 3 × 5 ANOVA (3 × condition – SS, FR, FR+SS, 5 × time – pre, post, 10, 15, and 20 minutes) for repeated measures was used. Differences were considered significant at an alpha level of 0.05. The Greenhouse-Geisser correction was used if the assumption of sphericity was violated. If an interaction was found the analysis was continued with one-way ANOVA. If significant differences were observed in the one-way ANOVA testing, post hoc testing involving pairwise t-tests with Bonferroni correction were performed. Descriptive statistics were reported for reference, including means and standard deviation (Mean ± SD).

RESULTS

Within conditions

A significant time effect was found for SS (F (4,40) = 8.852, p < 0.05, partial \( \eta^2 = 0.470 \)), FR (F(4,40) = 3.149, p < 0.05, partial \( \eta^2 = 0.239 \)) and FR+SS (F (4, 40) = 9.277, p < 0.05, partial \( \eta^2 = 0.481 \)). Post hoc testing revealed increases in passive ankle dorsiflexion ROM between baseline and post-intervention by 6.2% for SS (p < 0.05) and 9.1% for FR+SS (p < 0.05) but not for FR. Post hoc testing did not reveal any other significant differences between baseline and any other time point for any intervention. The descriptive statistics for the increases in passive ankle dorsiflexion ROM with each intervention are provided in Table 1.

Between conditions

A significant effect of condition was observed immediately post-intervention (F (2, 20) = 4.179, p < 0.05, partial \( \eta^2 = 0.295 \)). Post hoc testing revealed that FR+SS was superior to FR (p < 0.05) for increasing passive ankle dorsiflexion ROM. Post hoc testing did not reveal any other significant differences between conditions at any other time point.

DISCUSSION

The acute effects of FR, SS and FR+SS of the plantarflexors on passive ankle dorsiflexion ROM in resistance-trained, adolescent athletes with at least six months of FR experience were compared. The

| Table 1. Acute increases in passive ankle dorsiflexion ROM following interventions involving FR, SS and FR+SS at different time points |
|---------------------------------|-----------------|------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                                | Pre (cm)        | Post (cm)        | Change at post (cm) | Change at 10 minutes (cm) | Change at 15 minutes (cm) | Change at 20 minutes (cm) |
| SS                             | 14.5 ± 3.5      | 15.4 ± 3.2       | 0.9 ± 0.67          | 14.9 ± 3.4          | 14.8 ± 3.5          | 14.7 ± 3.3          |
| FR                             | 14.5 ± 3.2      | 14.9 ± 3.4       | 0.4 ± 0.67          | 14.7 ± 3.4          | 14.8 ± 3.2          | 14.9 ± 3.1          |
| FR+SS                          | 14.3 ± 3.2      | 15.6 ± 3.2       | 1.3 ± 0.65          | 15.0 ± 3.3          | 14.9 ± 3.2          | 14.7 ± 3.0          |

Definitions: SS = static stretching; FR = foam rolling; FR + SS = foam rolling plus static stretching.
Time course of these acute effects at four time points within a 20-minute period post-intervention was also investigated. It was found that FR, SS and FR+SS all lead to acute increases in flexibility and that FR+SS has an additive effect in comparison with FR alone. It was also found that all three interventions (FR, SS and FR+SS) had time courses that lasted less than 10 minutes. The current investigation was unique in several important respects: the additive effect of SMR and SS has not previously been explored and SMR has not previously been studied in adolescents, in resistance-trained athletes, or in individuals accustomed to using SMR techniques.

**Comparison of FR, SS and FR+SS**

On the basis of previous research suggesting an additive effect of SMR and SS over a short-term period, it was hypothesized that FR+SS might be superior to FR and SS for increasing passive ankle dorsiflexion ROM acutely. This hypothesis was partially supported, as the increase in passive ankle dorsiflexion ROM in FR+SS immediately post-intervention was significantly greater to that observed in FR alone. However, the increase in passive ankle dorsiflexion ROM in FR+SS was not superior to that observed in SS alone. Since SS has been associated with acute, undesirable reductions in performance in sporting movements, while SMR has not, these findings may imply that it may be possible to perform a reduced volume of SS by supplementing with FR in order to achieve a similar increase in ROM. In turn, this may induce smaller decrements in performance measures for the same benefit to flexibility. However, the current investigation did not compare volume-matched SS, FR and FR+SS conditions and it is unclear how reducing the volume of SS and FR within the FR+SS condition would affect flexibility. Moreover, it is unclear how performance might be affected by volume-matched SS, FR and FR+SS conditions.

In addition, it is unfortunate that although the difference in the changes in passive ankle dorsiflexion ROM was statistically significant between FR+SS and FR, the standard error of measurement was 1.1 cm. This indicates that a difference of ±2.1 cm may be necessary to be confident about the accuracy of a single measurement. Moreover, the Minimum Difference (MD) to be considered real was 3.0 cm. Since the reported differences between conditions for the change in ankle dorsiflexion ROM were all less than the MD (<0.9 cm), this may suggest that the differences that were observed may be the result of measurement error (or chance) rather than an effect of the specific condition undertaken.

Nevertheless, it is informative to compare the current results with those of other investigators. While no previous acute investigation has explored the additive effects of SMR and SS in comparison with SMR or SS alone, at least two trials have directly compared the acute effects of SMR and SS with one another. Halperin et al compared the acute effects of roller massage and SS in 14 untrained subjects and found that both interventions led to significantly increased passive ankle dorsiflexion ROM. However, there was no significant difference between interventions. Howe et al compared the acute effects of SS and FR on hamstring flexibility as measured by sit-and-reach performance in 10 untrained subjects. Again, there were no significant differences between groups although the increases in sit-and-reach performance were non-significant in both groups, which may indicate a lack of sufficient statistical power.

The way in which FR+SS might display an additive effect beyond that observed in FR is unclear. By the observation of an additive effect, it may be the case that the mechanisms by which SS and FR increase flexibility are different or it may be that the greater stimulus led to a bigger increase in joint ROM. While the mechanism by which SS increases flexibility has historically been subject to some controversy, many researchers now maintain that the predominant means by which SS exerts its effects are central rather than peripheral and that increased stretch tolerance is the primary mechanism. Similarly, the mechanisms by which SMR are currently thought to be effective are also neural. Indeed, increased stretch tolerance is one of the proposed mechanisms for improvements in ROM in a joint after a bout of massage. A number of trials have investigated the acute effects of SS duration or volume on flexibility and have reported conflicting results. Some studies have reported greater increases with longer durations of SS, while others have not. In respect of SMR, only one trial has directly assessed the acute effects of different volumes of SMR on flexibility. Sullivan et al compared the acute effects of four
Several previous studies have explored the time course of increases in flexibility following an acute intervention of either SS or SMR alone but no previous trial has investigated a combined intervention as is reported here. Regarding the time course of the acute effects of SS on flexibility, the current results differ from those of Halperin et al., who reported increases that persisted up to 10 minutes post-intervention. However, the current findings are in agreement with those of Ryan et al. and DePino et al., who both found that increases in joint ROM returned to baseline within 10 minutes post-intervention with SS. Regarding the time course of the acute effects of FR on flexibility, the current results differ from those of Halperin et al., who used a roller massager on the ankle plantar flexors and reported increases at 10 minutes post-intervention in addition to one minute post-intervention, and MacDonald et al., who used a foam roller on the quadriceps and also reported increases at 10 minutes post-intervention in addition to two minutes post-intervention. However, the current findings are in agreement with those of Jay et al., who also used a roller massager on the hamstrings and found that while flexibility was greater immediately post-intervention, the effects were lost after 10 minutes. For both SS and FR, there are various factors that could theoretically explain differences between trials, including the population, the precise measurement method used for joint ROM, the muscle group being treated, and either the nature, intensity, volume and method of application of the SMR tool, or the intensity and volume of the SS, respectively.

Time course of FR, SS and FR + SS
On the basis of previous research suggesting an additive effect of SMR and SS over a short-term period, it was hypothesized that the duration of FR + SS might exceed that of SS and FR alone. This hypothesis was not supported. Significant main effects for time for each of FR, SS and FR+SS were found but post hoc testing revealed that increases in passive ankle dorsiflexion ROM were only significant between baseline and immediately post-intervention and only in SS and FR+SS. There were no significant differences between baseline and measurements taken at 10, 15 or 20 minutes in any condition. While it seems likely that the increase in FR was also only significant immediately post-intervention and therefore that there was no difference between interventions in relation to the time course of effects, the possibility cannot be ruled out that the modalities differed in this respect. The absolute increase in passive ankle dorsiflexion ROM immediately post-intervention in the FR condition was 0.4cm, which was very similar to the increase observed by Halperin et al. of 0.46cm at 1-minute post-intervention (Dr. David G. Behm, email communication, May 31, 2014) and therefore the lack of significant findings may relate to a difference in the number of subjects used in the two trials (14 vs. 11 individuals) and the resulting difference in statistical power.
experience, which classifies them as intermediates for these purposes. Few previous researchers have explored the differences in acute effects between trained and untrained individuals following a SS intervention and no previous trial has compared the acute effects of SMR alone or in combination with SS between individuals of differing training status. It is therefore unclear to what extent training status might have affected the current results. It is interesting to note that when Abdel-aziem and Mohammad compared the long-term effects of SS in trained and untrained subjects on active ankle dorsiflexion ROM, they reported that while flexibility increased significantly in untrained individuals, no similar effect was found in trained subjects. Whether this same disparity would be observed in respect of acute effects, however, is unclear.

Regarding the intensity of application of SS, instructions used in the current investigation indicated that the subject should stop at the point of pain, while Halperin et al instructed their subjects to stretch to a level of 7 out of 10. This difference in stretching intensity might well account for the longer-lasting effects observed by Halperin et al, although the literature directly comparing the acute effects of different intensities of stretching is conflicting. In a trial comparing intensity of stretching of the ankle plantarflexors with either 100% and 90% of intensity by reference to pain, Young et al found no differences between conditions on the acute increase in ankle joint ROM. In contrast, Chagas et al compared maximal SS and sub-maximal SS comprising four repetitions for the hamstrings of 15 seconds each. They reported that while the maximal SS condition played a significant difference in respect of the acute increase in joint ROM from pre-test to post-test, the sub-maximal SS condition did not. More recently, Freitas et al explored three different intensities of stretch measured by reference to the maximal tolerable torque of the first repetition without pain: 50%, 75%, and 100%. They found that only the stretch at 100% of maximum tolerable torque increased joint angle ROM. Regarding the intensity of FR, the current investigation required the subjects to exert as much pressure on the foam roller as possible. In contrast, Halperin et al instructed the subjects to apply pressure equivalent to a pain level of 7 out of 10, Jay et al required their subjects to perform SMR with a moderate pressure, and MacDonald instructed the subjects to place as much of their body mass as possible upon the foam roller. No previous investigations have explored the combination of SMR and SS interventions, nor have any other studies investigated the effects of intensity of SMR on acute increases in flexibility.

The amount of pressure exerted during SMR might be a function of the tool used and the muscle group. MacDonald et al used a custom-made foam roller that was constructed of a hollow polyvinyl chloride (PVC) pipe covered in neoprene foam and treated the quadriceps. Jay et al did not describe the exact nature of the SMR tool but described it as a foam roller and applied it on the hamstrings. Halperin et al used a roller massager and applied it to the ankle plantarflexors, as in this study. The technique of foam rolling on the the quadriceps and hamstrings may allow the ability to apply a greater proportion of body mass to the foam roller and consequently a greater pressure to the underlying tissue.

**Limitations**

This study was limited in several important respects. Firstly, while the subjects were experienced in the use of FR, they did not have direct previous experience of the exact FR tool used in the trial, the The Grid Foam Roller. In the six-month period prior to the start of the trial, the subjects were accustomed to using harder and denser SMR treatment by using PVC pipes. Secondly, the number of attempts to achieve the maximum ROM of the ankle joint during the passive ankle dorsiflexion ROM test were not limited. Since Atha and Wheatley reported that there exists a mobilising effect of repeated measurements of joint ROM, this may have led to an interference effect whereby those subjects who performed more attempts achieved greater increases in flexibility. Thirdly, SS was performed with an extended knee, which may have exerted a greater effect on the biarticular gastrocnemius and a lesser effect on the monoarticular soleus. In contrast, the weight-bearing lunge test of passive ankle dorsiflexion ROM used for measurement was performed with a flexed knee and ROM may have been primarily restricted by the soleus and not by the gastrocnemius. Therefore, it is possible that using a SS protocol with a flexed knee may have led to superior acute increases in flexibil-
CONCLUSION
The acute effects of FR, SS and FR+SS of the plantarflexors on passive ankle dorsiflexion ROM in resistance-trained, adolescent athletes with at least six months of FR experience were investigated. FR, SS and FR+SS all lead to acute increases in flexibility and FR+SS had an additive effect when compared with FR alone, although by reference to the SEM and MD, it could be that this difference is the result of either error or chance. All three interventions (FR, SS and FR+SS) had time courses that lasted less than 10 minutes. Future research should explore whether there are differences in the acute responses to FR, SS and FR+SS between subjects who are familiar with FR and SS, respectively, as well as whether the additive effects of FR+SS are a consequence of the greater volume of treatment.

REFERENCES


ABSTRACT

Background and Purpose: Weight-bearing foot structure may influence postural control by either decreasing the base of support (BOS) or increasing the passive instability of the joints of the foot. Poor postural control has been implicated as the main causative factor for foot and ankle injuries. The purpose of this study was to examine the influence of forefoot postures on postural stability during single limb stance.

Methodology: Sixty healthy individuals between the ages of 18 to 31 were selected using a purposive sampling procedure based on forefoot angle measurements and categorized into three groups; high forefoot varus (≥8°) (n = 20), neutral forefoot varus (1° - 8°) (n = 20) and low forefoot varus group (≤1°) (n = 20). Static foot measurements, including relaxed rearfoot angle and navicular drop, and foot dimensions were performed. Height and weight were also recorded for all the subjects. Center of Pressure (COP) excursion in Anterior-posterior (AP) and Medial-lateral (ML) planes and Stability Index (SI) with eyes open and eyes closed conditions were also measured using the force platform.

Results: Strong correlations were found between forefoot angle and rearfoot angle (r = 0.71, p<0.01), forefoot angle and navicular drop (r = 0.58, p<0.01), and between rearfoot angle and navicular drop (r = 0.661, p<0.01). There were no correlations (p>0.05) between the forefoot angle and all the five COP measures, except between forefoot angle and SI with eyes closed (r = -0.25 p<0.01).

Conclusion: There is a significant positive correlation between forefoot angle and rearfoot angle and between forefoot angle and navicular drop. Forefoot angles did not affect the maximum AP COP and ML COP excursions or SI in healthy subjects.

Level of evidence: 3

Key words: Center of pressure, forefoot varus, navicular drop, postural control, rearfoot angle, stability index.
INTRODUCTION
Postural control is the control of the body's position in space for the purpose of balance and orientation. Static postural control is the ability to stabilize or minimize the movement of the center of gravity within the base of support (BOS) when equilibrium status has been achieved for a given weight-bearing position. Human standing posture is maintained through a central postural mechanism assisted by sensory feedback from labyrinthine, visual, muscular and cutaneous origins that together contribute to postural stabilization as well as comprise the basis of a body posture representation. The musculature of the legs, feet, and trunk use this feedback circuit, allowing the individual to stand erect against the forces of gravity. Generally, to maintain an upright stance, the central and peripheral components of the nervous system are constantly interacting to control body alignment with the center of gravity within the base of support. The proprioceptive system acts through the tactile senses of touch, pressure, and vibration and through the sense of position, which together help determine the relative positions and rates of movement of parts of the body. Center of Pressure (COP) is defined as the point on the foot at which the body weight is equally distributed between the medial-lateral (ML) and anterior-posterior (AP) quadrants and is recorded in centimeters. Movement of the COP in the ML and AP directions reflects the body's attempt to maintain postural control. There is a positive correlation between poor postural control and risk of injury in athletic population.

The human foot serves to balance the individual directly or indirectly during a variety of static and dynamic activities such as standing, walking, running, swimming, and diving. During a static or dynamic stance, the foot is a “mobile adaptor” which provides optimal function with minimal risk of injury. The foot is the only direct source of contact with a supporting surface and therefore it plays an important role in all weight-bearing tasks. When the components of foot effectively work together, it provides a balanced foundation for the body. Changes to foot structure, therefore, have the potential to alter the load distribution functions of the foot. Malalignments in the structures of the forefoot, midfoot, and rearfoot are thought to lead to compensatory motion, which may ultimately result in injury. Structural and positional imbalances of the foot may contribute to overuse injuries throughout the kinetic chain. Furthermore, it is suggested that the forefoot should be normally aligned perpendicular to the bisection of the calcaneus when the foot is in subtalar joint neutral. The subtalar joint neutral position has been considered to be an important reference position from which motion can be measured. Subtalar joint neutral position is defined as a navicular angle between 130° and 150°, a normal medial longitudinal arch, and a calcaneal position perpendicular to the ground. Any deviation from this position, either varus or valgus, is considered abnormal and could lead to abnormal motion and potential injury. However, recent studies have suggested that a certain variation in forefoot varus or valgus may be normal in an adult population.

A forefoot angle (FFA) measurement, usually performed in a non-weight bearing position, ranging between 1-8 degrees is considered neutral/normal and higher or lower than this range results in a description of high forefoot varus (i.e., ≥8˚) or low forefoot varus (i.e., ≤1˚). If the FFA is more than 8˚ (or in the inverted position of the foot on the calcaneus), the midtarsal joints are completely pronated during weight-bearing. This results in decreased osseous stability in the midtarsal joints and an inadequately rigid foot which leads to excessive hyper mobility of the subtalar joint and midtarsal joint during weight-bearing. Previous authors have shown that abnormal foot posture, such as an excessive pronation, is a predisposing and/or causative factor for several foot and lower limb dysfunctions such as those that may lead to anterior cruciate ligament injury. Likewise, when the FFA is <1˚ i.e., in everted position of the forefoot on the heel, the midtarsal joint is supinated and more of the lateral aspect of the foot is brought into contact with the ground resulting in less plantar contact area. This leads to reduced sensory input from plantar sensory end organs thereby reducing sensory input that is important for controlling or maintaining balance. Therefore, clinical assessment of foot posture may be an essential component for the management of any lower limb pain or dysfunction.

The influence of forefoot structure on weight-bearing midfoot and rearfoot positions has not been
extensively investigated. In addition, the influence of foot structure on postural control has not been well investigated. Thus, for the prevention of injuries, better understanding of the variables that influences postural stability may be useful. The objective of this study is to examine the influence of forefoot postures, (i.e., high, low and neutral forefoot types) on postural control during single limb stance, in both eyes closed and eyes open conditions. A secondary purpose was to investigate the relationship between forefoot types, a person's height, foot dimensions, and associated positions in the midfoot and rearfoot. It was hypothesized that types of forefoot postures would affect postural stability and there would be a significant relationship between static forefoot postures and the midfoot and rearfoot postures during stance.

METHDOLOGY

Participants
Sixty healthy subjects between the ages of 18 to 31 were selected using a purposive sampling procedure. One hundred and fifty four healthy volunteers were screened in order to enroll 60 subjects comprising three equal groups based on their forefoot measurements in prone lying position. Male and female subjects who had no history of lower extremity injury or pain in the six months prior to participation, could follow commands, and had no diagnosis of any neural or vestibular disease or lower extremity arthritis were included in the study. Any subject who had engaged in exercise or training that might require good postural control ability (e.g., ballet and gymnastics) during the previous year were excluded from this study. Subjects who used substances which might affect postural stability (e.g., alcohol, sedatives, cold remedies, and stimulants) were also excluded. Also excluded were those subjects who had congenital or acquired musculoskeletal deformity. The institutional review board of the study center approved the testing procedures and all participating subjects signed an informed consents prior to their participation.

Procedure
For all participants, forefoot angles (FFA) in subtalar joint neutral position and in prone lying position were measured using standard measurement procedures (Figure 1). The subjects were then divided into three groups with 20 subjects in each group, based on their FFA measurements. The groups were: High Forefoot Varus (HFV) group in which participants had varus greater than or equal to 8°, Neutral Forefoot Varus (NFV) group with varus between 1.0° and 8.0° and Low Forefoot Varus (LFV) group with less than or equal to 1.0° varus.

Static foot measurements, were collected for all subjects including the Relaxed Rearfoot Angle (RFA) and the Navicular Drop (ND), which have been proven to be reliable and valid. Height and weight of each individual was also recorded. All static measurements were performed by one investigator. The intra-tester reliability was not assessed but has been reported to be good in similar studies. A foot template for each subject was constructed to ensure the same foot placement for all standing measurement procedures. Each participant was asked to walk along a path of 4-m length at his/her preferred speed and come to a stop on a 45cm × 60cm piece of paper. Subjects were asked to end their walks in a bilateral stance with both lower limbs in a foot placement angle that was most comfortable to them. Two practice trials were allowed and on the third trial, after the subject came to standstill, each foot was traced

Figure 1. Forefoot angle measurement
on the paper with a marker or ballpoint pen to make the foot template. The length and width of each of the subjects' feet from the foot templates were measured in centimeters (cms). (Figure 2) All subsequent standing measures were taken with the subjects standing on the foot template to ensure that the same foot placement was used for all the measures.

The ND is the difference in navicular height measured in millimeter (mm) during subtalar joint neutral and relaxed stance. (Figure 3). The navicular height was measured in subtalar joint neutral and relaxed stance. Initially, the navicular bone of each foot was palpated when patient was sitting with feet supported and a mark was made with a marker on the most prominent aspect i.e., navicular tuberosity. Then, with the subject standing on a 6" wooden box, in his/her foot template, in bilateral stance, the subtalar joint in neutral position was palpated. An index card was placed vertically along the medial aspect of the foot and a mark was made on the card at the level of marked navicular. Each subject was asked to lift one foot off the box, bending the knee, and the navicular position was again checked on the index card during relaxed unilateral stance. The difference between these two measurements was utilized as the ND score.

For the Rearfoot Angle (RFA) measurement, first, longitudinal bisection lines were drawn with a marker along the posterior aspect of the lower third of the leg and the calcaneus for the bisection of the lower one-third of the leg and the bisection of the calcaneus with the subject in prone. Then, the subject stood in his/her gait template, on the box, in unilateral stance. The relaxed RFA was measured as the angle between the bisection of the lower one-third of the leg and the bisection of the calcaneus and measured in degrees (°). (Figure 4). All the standing
measures were taken with subjects standing on the foot template to ensure that the same foot placement was used for all the measures. All the measurements were taken three times and an average of those measurements was used as the RFA score.

The balance ability of each individual including max Center of Pressure (COP) excursions in AP and ML directions, and stability index (SI) was measured using a force platform which was supplied by Bertec© Force Platform (Columbus, OH, USA). All the force platform measures for single leg stances were taken with participants standing barefoot on the force platform in two conditions, eyes open and eyes closed. All measurements were taken three times and averages were calculated. Each participant performed three 10-second trials of each condition. A longitudinal line was placed on the force platform in order to control the foot position during testing. The participants aligned the foot to be tested such a way that the longitudinal line bisected the calcaneus and the 1st and 2nd metatarsals. (Figure 5) The participants were then instructed to bend their non-weight-bearing limbs at the hips and knees and cross their arms over their chests. During the eyes-closed condition, participants assumed the test position, closed their eyes, and gave verbal signals for their readiness. During testing the subjects were instructed to attempt to maintain their positions as motionless as possible without their non-weight-bearing limb touching either the ground or their weight-bearing limb. They were also instructed to not use their arms for balancing. If balance was lost, the participants were instructed to resume the initial testing position as quickly as possible. When the non-weight-bearing limbs touched the ground, the score was excluded from data analysis.

**Statistical Analysis**

The data for all parameters were recorded on a data collection form and then converted to tabular form. Means, standard deviations, standard errors and Karl Pearson Product Moment Coefficients (r) were determined to examine the relationships between the static foot measures, foot dimensions, and the force plate measures in high, neutral and low forefoot varus groups. Separate one-way analyses of variances (ANOVA) were used to investigate the differences in the static foot measures, COP excursions in AP and ML directions, and SI scores in single-limb stance score among the three forefoot type groups. Multiple comparisons were performed using bonferroni post-hoc corrections to test for significant differences between the three groups. Independent sample t-tests were used to investigate the within-subject variability in eyes open and eyes closed conditions within different forefoot varus groups. The level of significance was set at p < 0.05 for each analysis. All statistical analysis was performed using SPSS, version 20.0.

**Results**

Sufficient potential subjects were screened in order to reach a sample size of 20 participants in each group and maintain a 50% male and 50% female ratio. Some potential subjects who met the criteria for the neutral forefoot varus group were excluded from the study because a sufficient number of subjects had already been enrolled in this group.

Table 1 shows the descriptive statistics for baseline characteristics including age, height, weight and foot dimensions among the three groups. No significant

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*Figure 5. Force platform measurement procedure*
Among the sixty subjects, relationships were analysed between the static forefoot angle, weight-bearing midfoot position, height, weight, foot length, and foot width (Table 3). Results showed significant positive correlation between FFA and RFA ($r=0.71$, $p=0.000$) and between FFA and ND ($r=0.58$, $p=0.000$) (Figure 6), while there was a lack of correlation ($p>0.05$) between height ($r=-0.03$), weight ($r=0.17$), foot length ($r=0.04$) and foot width ($r=0.07$). RFA had a significant positive correlation with ND ($r=0.661$, $p=0.000$) and a weak correlation with weight ($r=0.30$, $p=0.03$), while no correlations were found between height, weight and foot dimensions. Significant weak negative correlations ($p<0.05$) were found between FFA and SI eyes closed ($r=-0.25$) and differences ($p>0.05$) were found in terms of these baseline characteristics between the groups. This shows the homogeneity of the subjects among the groups on baseline characteristics. Table 2 shows the descriptive statistics for static foot angles and navicular drop (ND) among the three subgroups. Table 2 also shows the descriptive statistics for COP measures i.e., AP and ML excursion and SI in both eyes open and eyes closed conditions among the three subgroups. A significant difference ($p<0.001$) was found between RFA and ND measures between the groups. The values differed in all the pair-wise comparisons between those three groups. However, no significant difference ($p>0.05$) were found in all of the force plate parameters among the groups.

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### Table 1. Descriptive statistics for baseline characteristics among 3 forefoot subgroups

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Male/Female</th>
<th>Age (year)</th>
<th>Height* (cm)</th>
<th>Weight* (kg)</th>
<th>Foot length* (cm)</th>
<th>Foot width* (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFV</td>
<td>20</td>
<td>10/10</td>
<td>20.7(1.45)</td>
<td>161(9.52)</td>
<td>59.86(11.84)</td>
<td>24.37(1.70)</td>
<td>9.68(0.78)</td>
</tr>
<tr>
<td>NFV</td>
<td>20</td>
<td>10/10</td>
<td>22.95(2.32)</td>
<td>164(10.2)</td>
<td>60.74(11.95)</td>
<td>24.72(1.68)</td>
<td>9.62(0.69)</td>
</tr>
<tr>
<td>LFV</td>
<td>20</td>
<td>10/10</td>
<td>20.4(1.56)</td>
<td>162(7.33)</td>
<td>54.48(7.45)</td>
<td>24.15(1.05)</td>
<td>9.46(0.75)</td>
</tr>
</tbody>
</table>

HFV= high forefoot varus; NFV= Neutral forefoot varus; LFV= Low forefoot varus
Values reported as Mean (SD), *- No significant difference (ANOVA) was found between the groups.

### Table 2. Descriptive statistics for static foot angles and forceplate measurement parameters among 3 forefoot subgroups

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>FFA* (°)</th>
<th>RFA* (°)</th>
<th>ND* (mm)</th>
<th>APSEO (cm)*</th>
<th>APSEC (cm)*</th>
<th>MLSEO (cm)*</th>
<th>MLSEC (cm)*</th>
<th>SIEO (%)*</th>
<th>SIEC (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFV</td>
<td>20</td>
<td>9.75(1.05)</td>
<td>15.2(2.38)</td>
<td>11.47(1.72)</td>
<td>1.25(0.3)</td>
<td>2.52(0.99)</td>
<td>1.02(0.31)</td>
<td>2.21(0.17)</td>
<td>86.24(2.93)</td>
<td>72.5(10.02)</td>
</tr>
<tr>
<td>NFV</td>
<td>20</td>
<td>4.59(1.87)</td>
<td>11.07(1.80)</td>
<td>6.69(1.52)</td>
<td>1.51(0.72)</td>
<td>2.72(1.68)</td>
<td>1.38(0.76)</td>
<td>2.06(0.67)</td>
<td>84.28(4.43)</td>
<td>73.41(8.32)</td>
</tr>
<tr>
<td>LFV</td>
<td>20</td>
<td>-3.21(1.94)</td>
<td>11.35(2.65)</td>
<td>9.15(2.54)</td>
<td>1.47(0.51)</td>
<td>2.17(0.5)</td>
<td>1.13(0.42)</td>
<td>2.04(0.6)</td>
<td>84.49(4.09)</td>
<td>75.7(4.79)</td>
</tr>
</tbody>
</table>

HFV= high forefoot varus; NFV= Neutral forefoot varus; LFV= Low forefoot varus
FFA= Forefoot angle; RFA= Rearfoot angle; ND= Navicular drop; APSEO= Anterior-posterior stability eyes open; APSEC= Anterior-posterior stability eyes closed; MLSEO= Medial-lateral stability eyes open; MLSEC= Medial-lateral stability eyes closed; SIEO= Stability index eyes open; SIEC= Stability index eyes closed.
Values reported as Mean (SD), *- Significant difference (ANOVA) was found between the groups.
neutral forefoot varus (p<0.001) and low forefoot varus (p<0.001) groups. This is illustrated in Figure 7.

No significant differences were revealed in the mean values of ML COP excursion within the high, neutral and low forefoot varus groups in both eyes open (F=2.43, p>0.05) and eyes closed (F=0.32, p>0.05) conditions. But, a significant within-subject difference was found for eyes open versus eyes closed conditions in the high forefoot varus (p<0.001), in neutral forefoot varus (p<0.001) and low forefoot varus (p<0.001) groups. This is illustrated in Figure 8.

There were no significant differences in the SI (Figure 9) within the high, neutral and low forefoot varus groups in both eyes open (F=1.56, p>0.05) and eyes closed (F=0.85, i.e., p>0.05) conditions. But, a significant within-subject difference was found for eyes open versus eyes closed conditions in the high forefoot varus (p<0.001), neutral forefoot varus (p<0.001) and low forefoot varus (p<0.001) groups.

Discussion

The human foot provides the only direct contact with the supporting surface and therefore plays an important role in all weight-bearing tasks. Changes in foot structure therefore have the potential to alter the load distribution function of the foot.18 It has been suggested that the forefoot should be aligned perpendicular to the bisection of the calcaneus when the foot was between RFA and SI eyes closed (r=-0.26), while no correlations (p>0.05) were found between the foot angles and all other COP measures in both eyes open and eyes closed conditions, and SI in eyes open condition (Table 4).

No significant differences were revealed within the high, neutral and low forefoot varus groups between mean values of AP COP excursion with both eyes open (F=1.483, p>0.05) and eyes closed (F=1.14, p>0.05) conditions. But, a significant within-subject difference was found for eyes open versus eyes closed conditions in the high forefoot varus (p<0.001), in neutral forefoot varus (p<0.001) and low forefoot varus (p<0.001) groups. This is illustrated in Figure 7.

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Table 3. Correlations between forefoot angle, foot measurement parameters and other variables among all the subjects

<table>
<thead>
<tr>
<th>Foot Angles</th>
<th>Pearson</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>RFA (°)</th>
<th>ND (mm)</th>
<th>Foot Length (cm)</th>
<th>Foot Width (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFA (°)</td>
<td>r</td>
<td>-0.03</td>
<td>0.17</td>
<td>0.71**</td>
<td>0.58**</td>
<td>-0.04</td>
<td>0.07</td>
</tr>
<tr>
<td>P level</td>
<td>0.85</td>
<td>0.20</td>
<td>0.000</td>
<td>0.000</td>
<td>0.77</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>RFA (°)</td>
<td>r</td>
<td>0.19</td>
<td>0.3*</td>
<td>1</td>
<td>0.66**</td>
<td>0.11</td>
<td>0.23</td>
</tr>
<tr>
<td>P level</td>
<td>0.16</td>
<td>0.03</td>
<td>-</td>
<td>0.000</td>
<td>0.41</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>ND (mm)</td>
<td>r</td>
<td>-0.09</td>
<td>-0.01</td>
<td>0.696**</td>
<td>1</td>
<td>-0.087</td>
<td>0.102</td>
</tr>
<tr>
<td>P level</td>
<td>0.51</td>
<td>0.93</td>
<td>0.000</td>
<td>-</td>
<td>0.511</td>
<td>0.436</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td></td>
</tr>
</tbody>
</table>

FFA= Forefoot angle; RFA= Rearfoot angle; ND= Navicular drop
** Correlation is significant at the 0.01 level. * Correlation is significant at the 0.05 level.

Figure 6. Correlation between static foot angles and other foot measurements. - mm – millimeters, Deg - Degree

between RFA and SI eyes closed (r=-0.26), while no correlations (p>0.05) were found between the foot angles and all other COP measures in both eyes open and eyes closed conditions, and SI in eyes open condition (Table 4).

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There were no significant differences in the SI (Figure 9) within the high, neutral and low forefoot varus groups in both eyes open (F=1.56, p>0.05) and eyes closed (F=0.85, i.e., p>0.05) conditions. But, a significant within-subject difference was found for eyes open versus eyes closed conditions in the high forefoot varus (p<0.001), neutral forefoot varus (p<0.001) and low forefoot varus (p<0.001) groups.
foot types, foot dimensions and associated positions in the mid-foot and rearfoot.

In this study sixty healthy subjects in the age group of 18 to 31 years were included. No significant difference was found in either height, weight, foot length and foot length between the three group subjects showed the homogeneity among the samples. Also gender did not play a role in the study due to equal distribution among the groups. It was assumed that there is a potential for data inflation when using measurements from both the right and left foot of in subtalar joint neutral. Any deviation from this position could lead to varus and valgus forces which can lead to compensatory motions. Malalignments in the structure of the forefoot, midfoot, and rearfoot are thought to lead to compensatory motions, which ultimately may result in injury. Therefore, clinical evaluation of foot posture may be useful for assessing and treating patients with lower extremity dysfunctions. This study, therefore, aims to find the influence of forefoot posture on postural control during single limb stance, in both eyes closed and open conditions. Also investigated was the relationship between forefoot types, foot dimensions and associated positions in the mid-foot and rearfoot.

In this study sixty healthy subjects in the age group of 18 to 31 years were included. No significant difference was found in either height, weight, foot length and foot length between the three group subjects showed the homogeneity among the samples. Also gender did not play a role in the study due to equal distribution among the groups. It was assumed that there is a potential for data inflation when using measurements from both the right and left foot of

<table>
<thead>
<tr>
<th>Foot Angles</th>
<th>Pearson APSEO (cm)</th>
<th>APSEC (cm)</th>
<th>MLSEO (cm)</th>
<th>MLSEC (cm)</th>
<th>SIEO (%)</th>
<th>SIEC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFA (°)</td>
<td>r -0.07 0.23 -0.04</td>
<td>0.217 0.065 -0.25*</td>
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<td></td>
<td></td>
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<tr>
<td>P level</td>
<td>0.571 0.08 0.746 0.097</td>
<td>0.623 0.05</td>
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<td></td>
</tr>
<tr>
<td>RFA (°)</td>
<td>r -0.06 0.197 -0.07</td>
<td>0.129 0.084 -0.26*</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P level</td>
<td>0.96 0.132 0.557 0.324</td>
<td>0.524 0.043</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ND (mm)</td>
<td>r 0.096 -0.201 0.046</td>
<td>-0.016 0.222 -0.089</td>
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<td></td>
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<tr>
<td>P level</td>
<td>0.466 0.124 0.729 0.904</td>
<td>0.888 0.499</td>
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<tr>
<td>N</td>
<td>60 60 60 60</td>
<td>60 60 60 60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- FFA = Forefoot angle; RFA = Rearfoot angle; ND = Navicular drop; APSEO = Anterior-posterior stability eyes open; APSEC = Anterior-posterior stability eyes closed; MLSEO = Medial-lateral stability eyes open; MLSEC = Medial-lateral stability eyes closed; SIEO = Stability index eyes open; SIEC = Stability index eyes closed.

Figure 7. Comparison of mean anterior-posterior COP excursion between eyes open and closed condition within 3 forefoot groups. Cms – centimeters, COP -Center of Pressure

Figure 8. Comparison of mean medial-lateral COP excursions between eyes open and closed condition within 3 forefoot groups. Cms – centimeters, COP -Center of Pressure
The forefoot alignment is within a neutral range, there may not be a need to compensate through the midfoot or rearfoot. Therefore, this study sought to examine the relationship between forefoot angle and navicular drop. The significant positive correlation ($r = 0.58$, $p < 0.001$) found between forefoot angle and navicular drop confirmed the results of a previous study. There was also a significant difference ($p < 0.01$) found in ND between the three forefoot groups in the current study. But, the results found by another group of researchers did not show any significant correlation ($r = 0.29$, $p > 0.05$). A possible limitation in using navicular drop is the potential for skin movement over the marked navicular tuberosity. In the current study the navicular tuberosity position was marked in subtalar joint neutral and it was not marked again during standing relaxed position. This may have resulted in underestimation of the true excursion of the navicular drop.

Positive correlations ($p < 0.001$) were found between rearfoot angle and navicular drop in all groups of subjects of the current study. Other researchers also found that navicular drop was a significant predictor of maximal rearfoot eversion. McPoil and Cornwall found in an earlier study that among 17 static measures, only navicular drop substantially affected maximum rearfoot eversion angle. This means that higher navicular drop values were significantly associated with changes in rearfoot eversions. In other words, ND influences the rearfoot position.

Differences in postural control during single-leg stance are typically examined either with side-to-side comparisons in unilaterally injured subjects or between healthy and injured subjects. Several studies have demonstrated no significant differences in postural control measures between the right and left limbs, or dominant and non-dominant limbs of healthy subjects in single-leg stance. A few researchers have examined the role of different foot postures on postural control. The current study has included measurements of maximum COP excursions in AP and ML directions and SI as measures representing the reactions to accelerations of the centers of mass, and compared the effect of forefoot types on postural stability. No significant differences ($p > 0.05$) were found in any of the COP and SI measurements between the three forefoot

![Figure 9. Comparison of mean values of Stability Index between eyes open and closed condition within 3 forefoot groups. Cms – centimeters, SI – Stability Index](image-url)
groups. It has been hypothesized that an excessively supinated or pronated foot posture may influence the somatosensory input via changes in joint mobility (hypo- or hyper mobility) or plantar foot surface contact area (excess or no arch) in order to maintain a stable base of support. The lack of significant differences in postural measures between subjects of differing foot types might be explained by compensatory balance strategies for each foot type.

The relationships between FFA and different COP measures (AP, ML, SI) with both eyes open and eyes closed conditions were analyzed. The results of this study showed a weak negative correlation between forefoot angle and SI in eyes closed condition (r = -0.25, p < 0.05). Other than that, no correlations (p > 0.05) were found between the forefoot angle and all other COP measures i.e., AP and ML COP excursions with both eyes open and eyes closed conditions, and in SI in eyes open condition. This indicates that different forefoot types by themselves were not associated with postural stability. This is likely due to the fact that postural control is a function of various systems, used together, in order to maintain postural stability or to maintain the center of gravity over the base of support. It is generally accepted that human standing posture is maintained through a central postural program assisted by various forms of sensory feedback such as labyrinthine, visual, muscular and cutaneous origin which together contribute to postural stabilization.

No significant differences in maximum AP excursions were found within the high, neutral and low forefoot varus group in both eyes open (p > 0.05) and closed (p > 0.05) conditions. Cobb et al showed that AP postural stability scores in the “more” forefoot varus (MFV) group are significantly higher than those of the “less” forefoot varus (LFV) group. They used standard deviations of the x-axis and y-axis ground reaction forces for their measures of stability, while the current study included maximum displacements in AP and ML directions and SI as stability measures. In their study, Cobb et al considered 7° as a reference value and divided subjects into HFV (FFA ≥ 7°) and LFV (FFA < 7°). Further, they only had 32 subjects who were not homogenously divided into two groups as compared to the current study where there were homogenous groups. In this current study, no significant interactions in maximum AP excursions and SI were observed within the high, neutral and low forefoot varus groups in both eyes open (p > 0.05) and eyes closed (p > 0.05) conditions. Cobb et al show that MFV group demonstrated greater ML stability scores compared to HFV group; however, this difference was not statistically significant. This provides lack of support for the first hypothesis in the current study because different foot postures did not significantly affect the postural stability. It is also possible that the postural control system of the body may function to reduce the velocity and acceleration of the body mass more than absolute displacement which reduces the body sway. This might explain the lack of significant impact of foot postures on COP measures.

One of the limitations of the current study is that only healthy individuals were included while subjects with plantar heel pain, other diseases, and elderly persons were excluded. In addition, this study has analyzed only the static relationships between foot postures and associated positions but did not consider the relationships between different foot postures during dynamic activities. These dynamic postural relationships pertaining to functional activities could be subjects of further study as they may help in predicting the injury profiles of individuals.

CONCLUSION
This results of this study indicate that positive correlations existed between forefoot angle, rearfoot angle, and navicular drop in healthy subjects while forefoot angle had no relationship to the maximum AP and ML COP excursions and SI in both eyes open and eyes closed conditions. Finally, visual input had a significant effect on maximum AP and ML COP excursions and for SI irrespective of varied forefoot varus angles.

REFERENCES


32. McPoil TG, Cornwall MW. The relationship between static lower extremity measurements and rearfoot


ABSTRACT

Background: Adherence to rehabilitation is widely accepted as vital for recovery and return to play following sports injuries. Medical management of concussion is centered around physical and cognitive rest, a theory largely based on expert opinion, not empirical evidence. Current research on this topic focuses on factors that are predictive of adherence to rehabilitation, but fails to examine if patient adherence leads to a better outcome. The purpose of this study was to determine the adherence tendencies of adolescents to treatment recommendations provided by a sports-medicine physician after a concussion and to determine if adherence to each recommendation was a predictor of treatment duration.

Study Design: Observational.

Methods: Participants were enrolled in the study at their initial visit to the Sports-Medicine Center for medical care after a sports-related concussion. Individual treatment recommendations provided by a sports-medicine physician for concussion were recorded over the course of each participant’s care. Once released from medical care, each participant was contacted to complete an online questionnaire to measure self-reported adherence tendencies to each treatment recommendation. Adherence was measured by two constructs: 1) the reported receptivity to the recommendation and 2) the frequency of following the recommendation. Exploratory univariate Poisson regression analyses were used to describe the relationship between adherence behaviors and the number of days of treatment required before the participant was returned to play.

Results: Fifty-six questionnaires were completed, by 30 male and 26 female adolescent athletes. The self-reported adherence tendencies were very high. None of the measures of adherence to the treatment recommendations were significant predictors of the number of days of treatment; however, there was a clear tendency in five of the six rest parameters (physical rest, cognitive rest with restrictions from electronics, and cognitive rest with restrictions from school), where high levels of adherence to rest resulted in an increased average number of days of treatment (slower recovery) and those who reported being less adherent recovered faster.

Conclusions: Adolescents were generally adherent to the physician recommendations. Those participants who reported being less adherent to physical and cognitive rest generally recovered faster than those who reported higher levels of adherence to these recommendations. As time progresses after the initial injury, physical and mental rest may be less effective to hasten recovery than more active treatment recommendations.

Level of evidence: Level 2

Key words: Adherence, adolescent, concussion, recovery, rest

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INTRODUCTION
Concussions are common in athletes who participate in junior high, high school, and college level sports. A concussion is defined as a complex pathophysiological process affecting the brain, induced by biomechanical forces. Management of sports-related concussion has become a controversial topic in literature with a variety of organizations producing position statements and recommendations. Current attention to this topic is warranted as concussion can cause symptoms that interfere with school, social and family relationships, and participation in sports. Appropriate management of concussion is therefore essential in reducing the risk of long-term symptoms and complications.

The goal of managing student athletes after a concussion is to hasten recovery while ensuring that the athlete is aware of all activities that may slow or hinder this process. Typical instructions and medical management provided to concussed athletes may include mental rest from electronics, mental rest with restrictions from school, physical rest (with restrictions from exercise and sport participation), prescription medication, physical therapy, or referrals to other medical specialists. Despite the medical recommendations provided to athletes, a retrospective study completed in 2009 demonstrated that 40.5% of concussed athletes in the United States were non-compliant with return to play guidelines, returning to contact physical activity without proper medical clearance. Non-adherence to physician recommendations and premature return to play can result in re-injury, more severe post-concussive symptoms, and other potentially devastating brain injuries, such as second-impact syndrome.

In all sports-related injuries, regardless of diagnosis, adherence to rehabilitation is believed to be vital for successful recovery and return to sport. Personal factors including self-motivation, pain tolerance, and athletic identity, as well as situational factors including peer support and stress level have been shown to predict adherence to rehabilitation after sports injury. Although these factors predicting positive adherence have been identified, current literature fails to examine if adherence does in fact lead to better outcomes, such as shorter recovery times.

Methods
Study Design: This is an observational study of the natural history and recovery after a sports-related concussion utilizing clinical data and data obtained through an online survey.

Ethical review: This study was approved by the Institutional Review Board at Akron Children's Hospital and the Human Subjects Review Board at Walsh University. Informed consent was obtained from the parent or legal guardian as well as an assent from those participants under age 18. Informed consent was obtained from participants who were 18 or older.

Sample: This convenience sample consisted of adolescent athletes (12-19 years of age) who were seen at Akron Children's Hospital Sports-Medicine Center, with a diagnosis of sports-related concussion. Patients were invited to participate if they sustained a concussion during the participation in a sport activity. Motor vehicle accidents or other etiologies for concussion were not included. Adolescents with history of previous concussions were included in this study as well as those with no previous concussions. Athletes were invited to participate in this study regardless of the time that had passed between the concussion and the first office visit to the Sports Medicine Center.

Data collection: The data collected included age, gender, Post-Concussion Score (PCS) at the initial medical appointment, and number of previous concussions. The sport where the concussion occurred and date of the concussive event was collected for each athlete. For each patient, the treatment recommendations that were provided to the patient over their course of care were recorded. This included recommendations for physical and mental rest,
treatment with medication, or referral to physical therapy or another specialist for follow-up care. Finally, the date when the patient was discharged from sports-medicine and returned to full contact play was recorded. In Ohio, a physician signature is required for return to play; thus, the date of recovery from the concussion was based on medical determination.

Following the end of medical care with sports medicine, the participant was contacted by e-mail to ask follow-up questions to measure self-reported adherence tendencies. The qualitative questions asked about receptivity to each treatment recommendation provided during their care at the sports medicine center and the frequency with which each recommendation was followed. These questions were modified from research conducted by Brewer et al that describes the Sport Injury Rehabilitation Adherence Scale (SIRAS).\(^{11}\) The original scale was derived from adherence literature and is based on clinician report of patient adherence tendencies during a clinical appointment.\(^{11}\) The modifications made for this research project enabled self-report of known constructs of adherence (i.e. “receptivity” and “frequency of following”) to concussion treatment recommendations.

An example of this query for each treatment recommendation is displayed in Figure 1.

Participants were queried in this manner about physical rest, mental rest with restrictions from school, mental rest with restrictions from electronics, recommendations for medication, referral to physical therapy, and referral to another specialist (neurologist, psychologist, or other).

**Statistical Analyses:** All statistical analyses were completed with Statistical Analysis Software (SAS) 9.3. Descriptive statistics for the sample were calculated. The number of days to assessment was calculated by subtracting the date of the initial appointment with sports-medicine from the date of the concussion. The primary outcome of interest, number of days of treatment, was calculated by subtracting the date of full contact return to play from the date of the initial assessment completed at the Sports Medicine Center. The total number of days to return to play was calculated by adding the days to assessment to the days of treatment, and measures total time the athlete was regarded to have a concussion before full return to play.

For the statistical analysis, each receptivity question was condensed from five categories on the survey down to three categories for the analysis. The responses “very receptive” and “receptive” were made into one category called “receptive” (i.e. open and willing to receive the recommendation) and the categories “very unreceptive” and “unreceptive” were made into one category called “unreceptive” (i.e. unwilling to receive the recommendation). The middle category, “neutral”, was unchanged. Each question on the frequency of following the recommendation was also condensed from five categories on the survey down to three categories for the analysis. The responses indicating “always” and “most of the time” were made into one category called “most of the time” and the responses “rarely” and “never” were made into one category called “rarely.” The middle category “sometimes” was unchanged.

Because this research was exploratory in nature, univariate Poisson regression analyses were completed, modeling the patient receptivity to each medical recommendation for concussion management and the frequency with which each recommendation was followed, individually. Injury characteristics, including initial post-concussion score, and demographic characteristics were also analyzed in this same manner.
to determine if these were significant predictors of the number of days of medical treatment. To control for the variance of the distribution assumption that the variance equals the mean of the predictor, PROC GENMOD with the repeated statement was used in all models to obtain robust standard errors for the Poisson regression coefficients.13

After the regression analyses were completed for each potential predictor, the coefficients obtained were placed in the model equation to determine the average number of days of treatment for the three levels of each predictor variable. This is the regression equation that was used to obtain the point estimate for the number of days of treatment for each predictor variable.

\[ \text{number of days of treatment} = \beta_0 + \beta_1 \]

**RESULTS**

A total of 111 participants were enrolled in the original study, treated at Akron Children’s Sports Medicine Center, and sent the final follow-up survey. Fifty-six questionnaires were returned and included in the data analysis for a response rate of 50.45%.

The descriptive statistics for the participants are shown in Table 1. Thirty males and 26 females were included in the study. The mean age of participants was 15 years with a majority being high school athletes. Within the sample, the concussions occurred during participation in a variety of sports, with a majority associated with football, basketball, soccer and other sports activities. Forty-four percent of the participants had at least one prior concussion. The number of days to assessment ranged from 1-89 days with a median value of seven days. The number of days to return to play ranged from 9-212, with a median value of 32.5 days. The number of days of treatment ranged from 2-208 with a median value of 25 days.

Of the medical recommendations provided to the participants, three encompassed rest constructs (physical rest, mental rest with restrictions from electronics, and mental rest with restrictions from school) and three encompassed additional interventions (medication, physical therapy or follow up with another specialist). All (100%) of the participants received recommendations for physical rest and of those, 40 (71.43%) reported receptivity to the recommendation and 49 (87.5%) reported that they followed the recommendation most of the time. Fifty-two (92.86%) received recommendations for mental rest with restrictions from electronics. Of these, 35 (67.31%) reported receptivity to the recommendation and 40 (76.92%) reported that they followed the recommendation most of the time. Forty-two (92.86%) of the participants received recommendations for mental rest with restrictions from school, 33 (82.93%) reported receptivity to the recommendation and 37 (90.24%) reported that they followed the recommendation most of the time (Table 2).

According to the results for the univariate Poisson regression analyses, none of the variables for measures of adherence to the recommendations for rest were significant predictors of the number of days of treatment. However, for the three recommendations of different types of rest (physical, mental with restrictions from electronics, and mental with restrictions from school) five of the six adherence parameters demonstrated that receptivity to the recommendation and following the recommendation most of the time resulted in an increased average number of days of treatment (slower recovery) and those who reported being unreceptive and rarely following the recommendations recovered faster.

Of those participants who were recommended additional interventions, 21 (38.18%) received recommendations for medication. Eighteen (85.71%) reported receptivity to the recommendation for medication and 19 (90.48%) reported that they followed the recommendation most of the time. Eighteen received recommendations for physical therapy, 13 (76.47%) reported receptivity to physical therapy, and 13 (76.47%) reported that they followed the recommendations from physical therapy most of the time. Nine (16.67%) participants received recommendations for a specialist referral, 8 (88.89%) reported receptivity to the recommendation, and 8 (88.89%) followed the recommendation most of the time (Table 2).

According to the results for the univariate Poisson regression analyses on these additional interventions, none of the measures of adherence to the recommendations for medication, physical therapy, or referral to a specialist were significant predictors of the num-
number of days of treatment. Additionally, there were not enough participants that were recommended these additional interventions to draw inferences on their association with the number of days of treatment. Additional factors analyzed through univariate regression were gender, total post-concussion score at the initial assessment, number of previous concussions, and level of competition (middle school, high school or college). The Poisson regression results exploring these additional characteristics of the sample in relation to recovery time demonstrated that none of the following predictors were significant predictors of the number of days of treatment: gender (p = 0.21), number of previous concussions (p = 0.68), initial post-concussion scale score (p = 0.24), or level of competition (p = 0.24).

**DISCUSSION**

There were two primary objectives of this research. The first objective was to determine adherence behaviors of adolescents to treatment recommendations

<table>
<thead>
<tr>
<th>Table 1. Descriptive Statistics for Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Continuous variables</strong></td>
</tr>
<tr>
<td>Age</td>
</tr>
<tr>
<td>Days to assessment</td>
</tr>
<tr>
<td>Days of treatment</td>
</tr>
<tr>
<td>Days to return to play</td>
</tr>
<tr>
<td>Post Concussion Symptom score at assessment</td>
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<tr>
<td><strong>Categorical variables</strong></td>
</tr>
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<td>Gender (male)</td>
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<td>Middle school</td>
</tr>
<tr>
<td>High school</td>
</tr>
<tr>
<td>College</td>
</tr>
<tr>
<td>Sport where concussion occurred*</td>
</tr>
<tr>
<td>Football</td>
</tr>
<tr>
<td>Soccer</td>
</tr>
<tr>
<td>Baseball/softball</td>
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<tr>
<td>Hockey</td>
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<tr>
<td>Cheerleading</td>
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<tr>
<td>Basketball</td>
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<td>Volleyball</td>
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<td>Wrestling</td>
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<tr>
<td>Swimming</td>
</tr>
<tr>
<td>Rugby</td>
</tr>
<tr>
<td>Other</td>
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<tr>
<td>History of previous concussions</td>
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<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>Physician recommendations</td>
</tr>
<tr>
<td>Physical Rest</td>
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<tr>
<td>Mental Rest from Electronics</td>
</tr>
<tr>
<td>Mental Rest with restrictions from School</td>
</tr>
<tr>
<td>Medication Rx</td>
</tr>
<tr>
<td>Physical Therapy</td>
</tr>
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<td>Specialist Referral</td>
</tr>
</tbody>
</table>

SD = Standard Deviation; does not add up to 56 because of missing data for one participant
Table 2. Univariate Poisson Regression of Adherence Behaviors and Number of Days of Treatment

<table>
<thead>
<tr>
<th>Variable</th>
<th>Patient Reported Statistics n, (%)</th>
<th>Regression Estimate (95% CI)</th>
<th>Average Number of Days of Treatment</th>
<th>p-value for Overall Significance</th>
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</thead>
<tbody>
<tr>
<td>Physical Rest – Receptivity</td>
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<tr>
<td>Receptive</td>
<td>40 (71.43)</td>
<td>Reference</td>
<td>39.25</td>
<td>.43</td>
</tr>
<tr>
<td>Neutral</td>
<td>11 (19.64)</td>
<td>-.09 (-.74, .57)</td>
<td>35.87</td>
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<tr>
<td>Unreceptive</td>
<td>5 (8.93)</td>
<td>-.41 (-.96, 14)</td>
<td>26.05</td>
<td></td>
</tr>
<tr>
<td>Physical Rest – Frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most of the Time</td>
<td>49 (87.50)</td>
<td>Reference</td>
<td>38.86</td>
<td>.29</td>
</tr>
<tr>
<td>Sometimes</td>
<td>6 (10.71)</td>
<td>-.39 (-1.0, 22)</td>
<td>26.31</td>
<td></td>
</tr>
<tr>
<td>Rarely</td>
<td>1 (1.79)</td>
<td>.03 (-.29, .35)</td>
<td>40.04</td>
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<tr>
<td>Mental Rest; Electronics – Receptivity</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receptive</td>
<td>35 (67.31)</td>
<td>Reference</td>
<td>33.78</td>
<td>.76</td>
</tr>
<tr>
<td>Neutral</td>
<td>11 (21.15)</td>
<td>-.10 (.33, -.73)</td>
<td>30.57</td>
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<tr>
<td>Unreceptive</td>
<td>6 (11.54)</td>
<td>-.23 (.31, -.83)</td>
<td>26.84</td>
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<tr>
<td>Mental Rest; Electronics – Frequency</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most of the Time</td>
<td>40 (76.92)</td>
<td>Reference</td>
<td>33.12</td>
<td>.23</td>
</tr>
<tr>
<td>Sometimes</td>
<td>8 (15.38)</td>
<td>-.37 (-.24, -.85)</td>
<td>22.87</td>
<td></td>
</tr>
<tr>
<td>Rarely</td>
<td>4 (7.69)</td>
<td>.31 (.36, .40)</td>
<td>45.15</td>
<td></td>
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<tr>
<td>Mental Rest; No school – Receptivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receptive</td>
<td>33 (82.93)</td>
<td>Reference</td>
<td>31.82</td>
<td>.80</td>
</tr>
<tr>
<td>Neutral</td>
<td>6 (14.63)</td>
<td>-.10 (.40, .89)</td>
<td>28.79</td>
<td></td>
</tr>
<tr>
<td>Unreceptive</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Mental Rest; No school – Frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most of the Time</td>
<td>37 (90.24)</td>
<td>Reference</td>
<td>32.46</td>
<td>.09</td>
</tr>
<tr>
<td>Sometimes</td>
<td>4 (9.76)</td>
<td>-.79 (.37, -1.51)</td>
<td>14.73</td>
<td></td>
</tr>
<tr>
<td>Rarely</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Medication – Receptivity</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Receptive</td>
<td>18 (85.71)</td>
<td>Reference</td>
<td>35.52</td>
<td>.24</td>
</tr>
<tr>
<td>Neutral</td>
<td>3 (14.29)</td>
<td>-.37 (.26, -.88)</td>
<td>24.53</td>
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</tr>
<tr>
<td>Unreceptive</td>
<td>-</td>
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<td>-</td>
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<tr>
<td>Medication – Frequency</td>
<td></td>
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</tr>
<tr>
<td>Most of the Time</td>
<td>19 (90.48)</td>
<td>Reference</td>
<td>35.52</td>
<td>.47</td>
</tr>
<tr>
<td>Sometimes</td>
<td>1 (4.76)</td>
<td>-.17 (.14, -.45)</td>
<td>29.96</td>
<td></td>
</tr>
<tr>
<td>Rarely</td>
<td>1 (4.76)</td>
<td>-1.08 (.14, -1.37)</td>
<td>12.06</td>
<td></td>
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<td>Physical Therapy – Receptivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receptive</td>
<td>13 (76.47)</td>
<td>Reference</td>
<td>52.46</td>
<td>.40</td>
</tr>
<tr>
<td>Neutral</td>
<td>2 (11.76)</td>
<td>.82 (.56, .27)</td>
<td>119.10</td>
<td></td>
</tr>
<tr>
<td>Unreceptive</td>
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<td>-.52 (.24, -1.00)</td>
<td>31.19</td>
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</tr>
<tr>
<td>Physical Therapy – Frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most of the Time</td>
<td>13 (76.47)</td>
<td>Reference</td>
<td>52.46</td>
<td>.40</td>
</tr>
<tr>
<td>Sometimes</td>
<td>2 (11.76)</td>
<td>.81 (.56, .27)</td>
<td>117.92</td>
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<tr>
<td>Rarely</td>
<td>2 (11.76)</td>
<td>-.52 (.24, -1.00)</td>
<td>31.19</td>
<td></td>
</tr>
<tr>
<td>Specialist – Receptivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receptive</td>
<td>8 (88.89)</td>
<td>Reference</td>
<td>54.05</td>
<td>.30</td>
</tr>
<tr>
<td>Neutral</td>
<td>1 (11.11)</td>
<td>-.62 (.18, .97)</td>
<td>29.08</td>
<td></td>
</tr>
<tr>
<td>Unreceptive</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Specialist – Frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most of the Time</td>
<td>8 (88.89)</td>
<td>Reference</td>
<td>54.60</td>
<td>.29</td>
</tr>
<tr>
<td>Sometimes</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Rarely</td>
<td>1 (11.11)</td>
<td>-.78 (.18, -1.12)</td>
<td>25.03</td>
<td></td>
</tr>
</tbody>
</table>

CI = Confidence interval; p-value for overall significance indicates if the variable was a significant predictor of the number of days of treatment. Receptivity is a self-reported qualitative measure of the subjects’ self-reported willingness to opennes to receive the recommendation (rated as “receptive,” “neutral” or “unreceptive”); the frequency of following the recommendation was a qualitative measure based on the self-report of how often they were complaint with the recommendation (rated as “most of the time,” “sometimes” or “rarely”).
after concussion. This was measured through self-reported receptivity to each recommendation they received from their sports-medicine physician and how frequently they reported following each treatment recommendation. In this study, it was demonstrated that for each of the recommendations provided by the sports-medicine physicians, the receptivity and frequency of following each recommendation was very high. Although little is established about the implementation of medical recommendations given to adolescents following a head injury, similar findings have been demonstrated in one of the only studies completed on adherence of adolescents to activity restrictions after concussion. Here, self-report diaries were used to measure physical activity, where at two different time points in the study, it was found that the participants reported 20% and 33% noncompliance, indicating the majority of participants did comply with the activity restrictions.14

The second objective of this study was to determine if participants’ adherence behaviors to each treatment recommendation are predictors of the number of days of treatment needed to recover from concussion and return to play. Despite the finding that there is no statistically significant relationship between the six examined physician recommendations and the primary outcome (number of days of treatment), a clear tendency was observed in the data indicating fewer days of treatment (faster recovery) when students were less adherent to the recommendations for physical rest, mental rest from electronics, and mental rest with restrictions from school. Other research has demonstrated this apparent iatrogenic effect of recommendations to strict rest. In terms of physical rest, it has been shown that while high intensity physical activity is correlated with an increased total symptom score and low neuropsychological performance, the same is observed for those who were restricted completely from exercise activity.15 Moderate levels of physical activity have been shown to be safe and provide the best outcome for adolescents recovering from acute or post-acute concussion, specifically in a closely monitored physical therapy program.15,16,17,18

Considering the impact of mental rest, findings vary greatly in terms of the relationship between cognitive rest and recovery after concussion. Gibson and colleagues found no statistically significant relationship between mental rest and symptom duration, reporting that those participants who received recommendations for cognitive rest had a longer recovery time,19 findings comparable to those in the current study. It has also been found that cognitive activity, ranging from complete rest to significant cognitive activity, has similar recovery progression, suggesting that while unrestricted activity may hinder recovery, outright restriction from cognitive activity is not necessary.20

Clearly, a gap in the literature exists to base best clinical practice for treating concussion and the effectiveness of these treatment strategies. This forces clinicians to support their treatment recommendations on vague advice such as, "In the absence of evidence-based recommendations, a sensible approach involves the gradual return to school and social activities (prior to contact sport) in a manner that does not result in a significant exacerbation of symptoms."4 The Zurich consensus statement goes on to propose that the cornerstone of concussion management is physical and cognitive rest until symptoms resolve, but specific treatment protocols in terms of the intensity or actual strictness of the demands related to physical and cognitive rest are not included.4 In light of this, experts are starting to question the practicality, even suggesting the detriment, of recommending strict physical and mental rest for all adolescents in the absence of supportive research evidence21, further speculating that a more aggressive and active treatment strategy under the supervision of a licensed physical therapist early in recovery may be of benefit.17,22,23

Exercise is considered an essential component of rehabilitation for sports-related injuries, sans concussion. Consensus statements1-4 and position papers5-7 all advise rest, but none support recommendations for type, degree, and duration of rest. They agree that adolescents should be "asymptomatic" at each stepwise progression of activity,14 but this poses an even further discrepancy as symptom reporting that occurs at baseline,24,25 as the result of exercise,26 with non-head related injury,27 due to mental health stressors, or from concussion can be quite similar. It has been shown in non-concussed and concussed athletes that symptom scores increased slightly from pre-exercise to immedi-
ately following moderate intensity exercise,\textsuperscript{26,28} and that a significant number of high school and collegiate athletes who report no symptoms after injury performed abnormally on neurocognitive testing (ImPACT),\textsuperscript{29} leading to the concept of being "asymptomatic" as a contradictory requirement for return to activity.\textsuperscript{26,27,28} Given these factors, and as no two concussions present exactly the same, safe resumption of physical activity must be overseen by qualified exercise professionals. Physical therapists can provide essential clinical skill in creating individualized treatment programs based on the patient presentation and response to treatment. Implementing supervised exercise in a sport's physical therapy setting allows adolescents to progress through their recovery safely while being monitored for any adverse reactions to activity.

The following limitations of the present study need to be taken into account. The population studied was a small, convenience sample taken from a single hospital setting and therefore the results may not necessarily be generalizable to a larger population. Adherence behaviors were obtained through a self-report measure, which may not represent the true adherence to the recommendations as self-report can over or under estimate true behavior.\textsuperscript{30} It is likely that those participants who completed the electronic survey were the most adherent to the recommendations and therefore, presents a selection bias whereby those who opted to participate in the survey may differ from the non-responders in ways that are immeasurable. Therefore, these findings not be representative of all adolescents with concussion. Secondly, although the primary outcome of interest, number of days of treatment, was determined by medical recovery (as deemed by a sports-medicine physician), this designation was determined at a follow-up appointment with sports-medicine. Because of this requirement, this may not represent the actual date of recovery. It is possible that recovery actually could have been established several days prior to the scheduled medical appointment. This potential delay in determination of recovery would be similar across all participants within this study. Based on this study, it is unknown if the individuals who were less symptomatic, with shorter recovery time were non-adherent for that reason, or if the participants with increased symptomatology, and a longer recovery time were compliant in hopes of improvement. Further research on the predictors of adherent behavior post-concussion and the effects of adherence to physical and cognitive rest needs to be completed to better understand this relationship.

CONCLUSION

For each of the recommendations provided by the sports-medicine physicians to the adolescent participants, the receptivity and frequency of following each recommendation was very high. There were no statistically significant relationships found between adherence tendencies and the number of days of treatment; however, a trend in the data was seen indicating fewer days of treatment when the adolescents were less adherent to the recommendations of physical rest, mental rest from electronics, and mental rest with restrictions from school. These findings are important and can be used in subsequent research aimed at determining optimal treatment recommendations following sports-related concussion. There is a strong need for high-level studies evaluating the effects of rest and activity for concussion management.

REFERENCES


22. Reneker JC, Cook CE. Dizziness after sports-related concussion: Can physiotherapists offer better treatment than just 'physical and cognitive rest'? *Br J Sports Med* Published Online First: 17 July 2014. doi:10.1136/bjsports-2014-093634


CASE REPORT

DIFFERENTIAL DIAGNOSIS AND MANAGEMENT OF AN OLDER RUNNER WITH AN ATYPICAL NEURODYNAMIC PRESENTATION: A CASE FOR CLINICAL REASONING

Jonathan Sylvain, PT, MPT, OCS, FAAOMPT
Michael P. Reiman, PT, DPT, OCS, SCS, ATC, FAAOMPT, CSCS

ABSTRACT

Study Design: Case Report

Background and Purpose: The purpose of this case report is to describe the clinical reasoning process involved with the differential diagnosis and management of a 69 year-old male runner reporting a six month history of insidious onset of left sided low back and buttock pain of low to medium degree of irritability. The case presented describes the utilization of clinical reasoning by a clinician in fellowship training when a patient with atypical adverse neurodynamic dysfunction related to running was encountered.

Case Description: The patient's physical examination was relatively unremarkable. Assessment of the patient's subjective history, self-report measures [Oswestry Disability Index (ODI), global rating of change scale (GROC)], objective findings, and tests and measures led to a working diagnosis of atypical adverse peripheral neurodynamic dysfunction. The lumbar spine, sacroiliac joint, hip joint and lower extremity were ruled out by a comprehensive subjective and objective examination. The diagnosis of adverse neurodynamic dysfunction became a diagnosis of exclusion.

Outcomes: Returning two and a half weeks after initial evaluation the patient reported no pain with running. Twelve weeks after the initiation of physical therapy, the patient was contacted via email. He was sent, and asked to fill out an ODI. The patient demonstrated an improvement in ODI from 10% to 2%. He also reported that he continued to run after treatment without pain.

Discussion: Determining the source of a patient complaint can occasionally be an arduous undertaking. Pathological sources of a patient's symptoms may not be easily determined. Development of differential diagnosis and clinical reasoning skills is imperative. Improving clinical reasoning skills requires deliberate practice through reflective thinking before, during, and after patient interactions. Refinement of these skills leads to the primary goal of identifying the patient's clinical presentation, thus matching it with the most effective treatment approach.

Level of evidence: Level 4

Key words: Differential diagnosis, nerve tension, physical therapy

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The authors report no potential conflicts of interest in the development and publication of this manuscript.

This case report was completed at the Duke University Medical Center, Physical Therapy Department, Durham, NC. At the time of the case, Jonathan Sylvain was completing a manual therapy fellowship under the mentorship of Dr. Reiman.

The subject was informed that data concerning the case was submitted for publication.
BACKGROUND/PURPOSE:
Physical therapists must conduct a thorough examination and evaluation, develop a hypothesis relating to the patients presentation, and select appropriate intervention(s) in order to provide optimal patient outcomes. The process of developing an accurate diagnosis involves sound clinical decision-making. A broad view of clinical decision-making can be viewed as being right or being wrong. Current clinical decision making models suggest that there is no right and wrong, rather that there are variations in the correctness of a clinician's clinical decision-making.1-3

Clinical reasoning is the process in which the clinician, structures meaning, goals, and health management strategies based on clinical data, patient choices, and professional judgment and knowledge.1 A definitive definition of clinical reasoning can be difficult, because it is a complicated and multifaceted process. In fact, no one definition captures the subtlety of how therapists think in the midst of practice.4

Clinical presentations encountered on a daily basis can range from well defined to multifactorial, which can be treated with simple or complex solutions. During each individual patient interaction, components of the clinical examination, including, but not limited to, subjective history, outcome measures, objective examination, and special testing, are assessments with their own ability to shift probability of a particular diagnosis. This is especially true of patients with pain in the lumbo-pelvic region, an area of suggested symptom convergence.5

The potential for symptom convergence in the lumbo-pelvic region may be due to the anatomical complexity and the potential numerous sources of pain in this region.6,7 A comprehensive assessment of any patient presenting with complaints of low back pain (LBP) and leg symptoms requires examination of both non-neural and neural tissues. Differentiating between mechanical versus nerve related structures can prove difficult as the extent of neural movements are commonly proportional to the extent of the surrounding tissue movement.8 An alteration in neurodynamics will clinically present as adverse neural tension. Therefore, any changes in neural physiology or mobility may result in the development of patient's symptoms.9

Neurodynamics is a concept that describes the dynamic interaction of the biomechanical, physiological, and morphological functions of the nervous system.10 Recognizing the neurophysiological mechanisms involved in a patient's pain state often proves challenging, even for expert clinicians. Therefore, examination of the nervous system requires a systematic clinical reasoning approach.

The purpose of this case study is twofold: First, to describe, evaluate, and discuss the clinical reasoning process utilized by a developing practitioner enrolled in a post professional fellowship when encountering an atypical patient presentation. Second, to present the examination and treatment of a patient presenting with atypical adverse neural dynamics related to running.

Case Description
Patient History

The patient was referred from a local orthopedic surgeon for the diagnosis of LBP and sciatica. The patient was a 69 year-old male reporting a six-month history of insidious onset of left sided low back and buttock pain of low to medium degree of irritability. Initial pain level reported by the patient was a 0/10, except for 5/10 with running and driving. The ODI was the primary patient reported outcome used in this case report. The patient's initial score was 10%. The ODI is scored from 0 to 100%. Zero equates to no disability and 100 indicates maximum disability. Secondary outcome measures included a 15-point global rating of change scale (GROC). His main complaint at the initial visit was aching left lower extremity posterior medial knee pain during running and left buttock/ left posterior medial knee pain while driving. The patient was an avid runner, running four to five times per week, two to three miles per run. The patient had attempted to run 10 days previous to the examination, but the pain began after running one half mile. He had not been able to run since. Ibuprofen helped decrease pain to a 0/10 when present after running or driving. No history of medical problems, past surgeries, or allergies was reported. Anterior-posterior and lateral radiographs of the lumbar spine revealed mild multilevel degenerative changes at the levels of L3 to S1 with slight retrolisthesis of L2 on L3 and mild lower lumbar
facet sclerosis. No evidence of scoliosis, spondylolisthesis, or other pathology was described on imaging report.

**Clinical Impression #1 (Table 1)**

Assessment of the patient’s subjective history, self-report measures, and diagnostic imaging led to the primary working hypotheses of lumbar stenosis, lumbar intervertebral disc herniation, and/or adverse neurodynamic presentation. Hip osteoarthritis, hamstring tendinopathy, and sacroiliac (SI) joint dysfunction were considered other possible sources of the patient’s pain. A thorough subjective history aided the therapist to rule out potential pathological conditions (Table 1). Through appropriate questioning the patient provided descriptions of the type of pain experienced and behavior of symptoms thus assisting in differentiating mechanical musculoskeletal dysfunction from pathological disorders.11 Plain film radiographs were unremarkable for fracture and the patient reported no history of trauma making the likelihood of fracture pathology improbable. The patient did not present with any signs and symptoms of cancer or visceral dysfunction and these conditions were also considered unlikely.

**Examination**

The examination included a postural assessment, lower extremity neurological screen, active and passive range of motion (ROM) assessments, manual muscle testing, lumbar/hip passive accessory testing, palpation of the hip and lumbar regions, and select special tests. Postural assessment revealed slightly rounded shoulders, increased thoracic kyphosis, and a forward head position. Gait assessment revealed a bilateral reciprocal, non-antalgic pattern without apparent dysfunction. The patient was able to perform a deep squat without reproduction of pain. He was able to get his thighs parallel to the floor and shins parallel to his trunk with this assessment. Lumbar flexion/extension, side bending, combined movements, and repeated lumbar flexion/extension ROM were all assessed and were negative for symptom reproduction. Lumbar ROM was within normal limits in all directions and over pressure was negative for symptom reproduction. Spinal mobility (as assessed with posterior-anterior passive accessory testing) did not reproduce the patient’s concordant pain and/or symptoms. Slump test elicited discordant pain, pain not similar to the patient’s pain complaint, in the lower back/pelvis region on the involved left side, as well as the uninvolved right side. Myotome and dermatome testing for bilateral lower extremities was normal. Deep tendon reflexes were normal and symmetrical. Upper motor neuron examination was deferred due to no suggestion that this type of testing was required. Bilateral hip joints demonstrated symmetrical and normal ROM, normal end-feel, and no symptom reproduction with over pressure in all planes. Palpation of the ischial tuberosity, greater trochanter, gluteus medius, illiotibial band, hamstrings, and SI joint was negative. Hip scour test was negative. Bilateral hamstring strength was 5/5 in prone at knee flexion angles of 40, 60, 90, 120 degrees. Straight leg raise (SLR) testing was 50 degrees bilaterally without symptoms. Straight leg raise testing with variations for peroneal, sural, and tibial nerves was negative bilaterally as well. The cervical spine was flexed during each variation of the SLR test to further sensitize (bias) the nervous system, but was negative in all variations. The thigh thrust test was negative bilaterally. Concordant pain was elicited with active hamstring stretching with the hip flexed at 90 degrees and foot dorsiflexed (Figure 1).10 A formal running assessment was not employed during the initial visit due to patient not having proper running clothing. The patient was advised to bring proper attire to the following visit.

**Clinical Impression #2 (Table 2)**

A plethora of diagnostic hypotheses were still present, resulting in the need for continued in-depth examination. Since lumbar neuro-musculoskeletal dysfunction was expected, the clinician began with a lower quarter screen. The early objective examination led to a low likelihood that the source of the symptoms was from lumbar stenosis or intervertebral disc herniation as the patient reported no increase or decrease of symptoms with sitting (except with sitting while driving), standing, or walking,12,13 demonstrated normal lumbar AROM in all planes including the lumbar quadrants14 with and without overpressure, and no pain with repeated lumbar motions.15,16 At this point in the examination, it was believed that the neural system should be examined in order to determine if the patient’s concordant sign, the activity
Table 1. Differential diagnosis following subjective history, self-report measures and diagnostic imaging.

<table>
<thead>
<tr>
<th>Symptoms</th>
<th>Hypothesis</th>
<th>Supporting Evidence</th>
<th>Negating Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lumbar stenosis</td>
<td>*Age (&gt;48 y.o.)*12</td>
<td>*Pain with sitting (no pain with sitting: SN 0.89)19</td>
<td><em>Symptoms were not improved when seated (symptoms improved with sitting: SP 0.86)12</em></td>
</tr>
<tr>
<td></td>
<td><em>(&gt;65 y.o) SP 69</em>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Increased with running</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Results of diagnostic imaging</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>(&gt;65 y.o) SP 0.89</em>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>*Pain with sitting (no pain with sitting: SN 0.89)*19</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>*Symptoms were not improved when seated (symptoms improved with sitting: SP 0.86)*12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lumbar intervertebral disc herniation</td>
<td><em>Subjective history of LBP with lower extremity radiation</em></td>
<td></td>
<td><em>No myotomal or dermatomal changes reported</em></td>
</tr>
<tr>
<td></td>
<td><em>Pain with prolonged sitting (specifically driving)</em></td>
<td></td>
<td><em>Age</em>60</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><em>(-) sciatica, SN 0.95</em></td>
</tr>
<tr>
<td>Adverse neuro dynamics (peripheral nerve entrapment)</td>
<td><em>Pain with sitting</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Subjective history of LBP with lower extremity radiation</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Subjective report of pain with running, specifically deceleration impact</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hamstring tendinopathy</td>
<td><em>Pain during running during eccentric contraction of the hamstrings</em>42,63</td>
<td></td>
<td><em>No reported pain with a standing hamstring stretch similar to the Puranen-Orava test (SN 0.76)</em></td>
</tr>
<tr>
<td></td>
<td><em>R posterior medial knee pain</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip osteoarthritis</td>
<td>*Age (&gt;50 y.o.)*59</td>
<td><em>No report of trauma</em></td>
<td><em>No limp or report of groin pain</em></td>
</tr>
<tr>
<td></td>
<td><em>History of lifetime involvement in high impact activities</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SI joint</td>
<td><em>No report of symptoms in SI region</em>28,29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertebral fracture</td>
<td><em>Age (≥ 50 y.o.) SP 0.61</em></td>
<td>*(-) radiographs (although not conclusive to R/O fracture)*64</td>
<td>*No pain with supine positioning (SN 0.81)*17</td>
</tr>
<tr>
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</tbody>
</table>
or motion that reproduced the patient's symptoms, could be replicated. Slump testing was assessed, eliciting discordant LBP that was comparable on the involved and non-involved sides and was not affected by a distant component. Slump testing was deemed negative due to not reproducing concordant pain and meeting the requirements for positive neural tension testing. With the finding of discordant pain during slump testing, further assessment of the nervous system was determined to be appropriate. Neurological testing (myotome/dermatome/reflex testing) was performed while in sitting. Findings were normal and symmetrical, providing further evidence to rule out intervertebral disc pathology and stenosis.

Neural testing in supine was assessed due to the patient's discordant pain during slump testing. Straight leg raise testing as described by Butler was performed and found to be negative. Frequently used sensitizing maneuvers, as described in the examination section, were initiated at the ankle and also assessed as negative. Due to the high sensitivity

Table 1. (Continued) Differential diagnosis following subjective history, self-report measures and diagnostic imaging.

<table>
<thead>
<tr>
<th>Visceral</th>
<th>Initially, non-reproducible pain</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Cardiopulmonary system</td>
<td></td>
</tr>
<tr>
<td>• Pelvic organs</td>
<td></td>
</tr>
<tr>
<td>• Digestive system</td>
<td></td>
</tr>
<tr>
<td>• Retroperitoneal region</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Non-mechanical</th>
<th>Initially, non-reproducible pain</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Malignancy</td>
<td></td>
</tr>
</tbody>
</table>

(-)=negative; LBP=low back pain; SI=sacroiliac; R/O=rule out

Figure 1. Active knee extension/dorsiflexion bias lower extremity neural assessment
<table>
<thead>
<tr>
<th>Symptoms</th>
<th>Hypothesis</th>
<th>Supporting Evidence</th>
<th>Negating Evidence</th>
</tr>
</thead>
</table>
| *R posterior buttock/posterior medial knee* | Adverse neuro dynamics (peripheral nerve entrapment) | - (-) hip joint screen<sup>19-21</sup>  
- (-) SI joint screen<sup>26</sup>  
- (-) lumbar spine screen<sup>15-15,67</sup>  
- Pain with sitting  
- Subjective report of pain with running, specifically deceleration impact  
- Reproduction of concordant sign with SLR sensitization maneuvers<sup>9</sup> | - (-) slump testing (SN 0.83,<sup>17</sup> 0.84<sup>46</sup>)  
- (-) SLR testing (SN 0.92,<sup>69</sup> 0.91<sup>70</sup>)  
- (-) SLR testing with sensitization for sural, peroneal, and tibial nerves |
|  | Lumbar intervertebral disc herniation | Subjective history of LBP with LE radiation  
- Pain with prolonged sitting (specifically driving) | Pain free lumbar AROM WNL with and without overpressure  
- (-) centralization (SN 0.92)<sup>44</sup>  
- (-) SLR test (SN 0.92,<sup>69</sup> 0.91<sup>70</sup>)  
- (-) slump test (SN 0.83,<sup>17</sup> 0.84<sup>46</sup>)  
- Normal myotomal screen  
- Normal reflexes  
- Non-antalgic stable gait |
|  | Lumbar stenosis | Age (>48 y.o.)<sup>12</sup>  
- Increased pain with running  
- Results of diagnostic imaging<sup>14</sup> | Pain free lumbar AROM WNL with and without overpressure (SN 0.70)<sup>13</sup>  
- (-) SLR test (SN 0.92,<sup>69</sup> 0.91<sup>70</sup>)  
- (-) slump test (SN 0.83,<sup>17</sup> 0.84<sup>46</sup>)  
- Normal myotomal screen  
- Normal reflexes  
- Non-antalgic stable gait  
- Pain with sitting |
|  | SI joint | Age (>50 y.o.)<sup>19</sup>  
- History of involvement in high impact activities | (-) thigh thrust (SN 0.88)<sup>26</sup>  
- (-) Fortin finger sign<sup>29,29</sup>  
- (-) pain to palpation at SI joint<sup>28,29</sup>  
- No report of symptoms in area |
|  | Hip osteoarthritis | Age (>50 y.o.)<sup>19</sup>  
- History of involvement in high impact activities | Pain free hip AROM WNL with and without over pressure  
- No report of trauma  
- No limp, groin pain, or limited IR<sup>19-21</sup> |
|  | Hamstring tendinopathy | Pain during running during eccentric contraction of the hamstrings  
- Right posterior medial knee pain  
- Pain with single leg deadlift<sup>15</sup> | (-) pain reproduction with resistive testing at knee angles of 40, 60, 90, and 120<sup>24,62</sup>  
- (-) pain with single leg bridge<sup>25</sup>  
- (-) tenderness to palpation along biceps femoris, semitendinosus, semimembranosus, and at ischial tuberosity<sup>7</sup>  
- No pain with taking-off-the-shoe test (SN 1.0)<sup>11</sup>  
- No pain with passive SLR, active knee extension or MMT of hamstrings (SN 0.95)<sup>34</sup>  
- (-) pain with modified bent-knee stretch (SN 0.89)<sup>22</sup> |

(-) = negative; SLR = straight leg raise; AROM = active range-of-motion; SI = sacroiliac; LE = lower extremity; LBP = low back pain; IR = internal rotation
of this test it appeared adverse neural dynamics was of low likelihood.

Possible hypotheses that had not been completely ruled out were hip osteoarthritis, hamstring tendinopathy, and SI joint dysfunction. After further examination hip osteoarthritis, hamstring tendinopathy and SI joint dysfunction were considered of low likelihood due to normal pain free hip ROM, negative bilateral scour testing, pain free and normal hamstring resistive and special testing, pain-free hamstring palpation, bilateral negative thigh thrust, negative Fortin finger testing, and pain free SI joint palpation.

Unable to distinctly reproduce the patients symptoms up to this point in the examination, and unable to assess running due to limitations in attire, the clinician decided to investigate the neural system further with expansion on foundational neurodynamic testing. Testing began with adding hip movements in various sequences, beginning with hip flexion, to SLR testing. According to Butler a commonly performed test is to flex the hip to end range and then add knee extension (and ankle dorsiflexion if necessary). Adding hip flexion was selected as the first movement to assess because of the patients functional complaints. Subjectively, the patient reported pain during the eccentric phase of knee extension while running when the hip was in a flexed position. This test elicited the patient's concordant sign with the addition of ankle dorsiflexion, and was different on the involved compared to the non-involved side. Therefore this test was assessed as positive. Ankle dorsiflexion was added prior to extending the knee. The patient's symptoms were further increased with this sensitizing procedure. Performing additional repetitions decreased the intensity of symptoms at end range.

Assessment of the patient's subjective history, self-report measures, objective findings, and tests and measures led to a working diagnosis of atypical adverse peripheral neurodynamics. The clinical reasoning that led this working diagnosis considered ruling out other structures as the source of the patient's symptoms. The likelihood that the patient's symptoms were originating from the lumbar spine, SI joint, hip joint or lower extremity was ruled less likely by a comprehensive and meticulous subjective and objective examination. In this case, adverse neurodynamics was a diagnosis of exclusion.

**Intervention (Table 3)**

After differentiating neural versus non-neural tissue as the pain generator, tensioning techniques were employed. Tensioning techniques are used to provide tension to the nervous tissue by pulling at both ends. The testing position that reproduced the patient's concordant sign was used as the treatment position. The patient was instructed to lie supine and flex the hip past 90 degrees. Once in this position he was instructed to extend his knee and dorsiflex the ankle to the point of concordant pain. This position was held for two to three seconds and repeated as described in Table 3. Since this was the only finding reproducing his pain, this was also instructed as his home exercise program (HEP). Clinical judgment led to the decision to employ tensioning versus gliding techniques secondary to the hypothesis that the neural system was unable to accept tension and the low degree of symptom irritability. The patient was

![Table 3. Interventions utilized in case report](image-url)

**Table 3. Interventions utilized in case report**

<table>
<thead>
<tr>
<th>Visit</th>
<th>Between Session Change</th>
<th>Intervention</th>
<th>Within Session Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>Active SLR 3 x 10 2-3x per day</td>
<td>Re-assessment sign: Active SLR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Instruction of jog (1 min)/walk (2 min) program</td>
<td>Decrease in intensity of symptoms at end range</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Desk ergonomics with specific focus on seated posture</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use of lumbar support when sitting</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>(2.5 weeks later)</td>
<td>Patient reports no pain in L buttock at this time with running</td>
<td>HEP/ergonomic review</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
</tbody>
</table>

SLR= straight leg raise; HEP=home exercise program; L=left; min=minute; N/A=not applicable
advised to monitor for worsening of symptoms with HEP. If symptoms worsened, the patient was advised to decrease the intensity of the exercise. If symptoms continued to worsen, the patient was advised to discontinue the activity. Additional instructions given are presented in Table 3. Secondary to a demanding work schedule it was decided that the patient would schedule a follow up visit for two to three weeks from the day of the initial evaluation. The treatment plan for the follow up visit was to assess the patient's response to his HEP as well as perform a running assessment.

The patient attended a follow up visit two and one half weeks after the initial evaluation. The patient reported compliance with his HEP and that his pain level had decreased allowing him to return to running. The patient wanted to review his HEP. He again stated that he did not bring running attire and did not think that it was necessary for a running or functional assessment to be performed since he had returned to running with no limitations and was satisfied with his outcomes.

Outcomes
Twelve weeks after the initiation of physical therapy, the patient was contacted via email. He was sent, and asked to fill out an ODI. The patient demonstrated an improvement in ODI from 10% to 2%, a minimal clinically important difference (MCID) of 8. The patient scored a +7 (a great deal better) on the GROC. Through email the patient reported that he continued to run without pain and that he was able to resume running the same distances he could prior to the onset of pain. He also reported no pain while driving. He could independently manage his symptoms and he was discharged with advice to continue with his independent HEP (Table 3). The patient was instructed and educated to call to schedule an appointment if his symptoms returned or any problems arose. (Table 4)

Discussion
This case report describes the utilization of clinical reasoning by a clinician in fellowship training examining and treating a patient with atypical adverse neurodynamics related to running. The clinician utilized a systematic, logical method of clinical reasoning when attempting to arrive at a differential diagnosis, based on reproduction of the patient's concordant pain. While the subjective history can be used to determine up to 76% to 83% of diagnoses, encountering a patient who presents with signs and symptoms not clearly delineating a specific pain generator renders clinical reasoning and differential diagnosis essential. The foundation of clinical reasoning is the ability of the clinician to recognize relevant cues and how they relate to one another. The patient's subjective and objective examination may make it possible to easily exclude potential diagnoses, but other diagnoses may require more detailed examination.

In this case, the subjective examination aided in ruling out potential pathologic conditions but did not clearly delineate a pain generator. Therefore, the clinicians reasoning processes were modified. This was demonstrated with the use of a progressive clinical examination. Steps were taken to sequentially rule out possible pain generators in the lumbo-pelvic region.

Clinical reasoning is dependent on two processes: 1) the analytic method, hypothetical deductive reasoning, and 2) the non-analytic method, pattern recognition. Integration of both processes allows for efficient and accurate clinical decision making. Pattern recognition should be considered a necessary building

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**Table 4. Outcomes scores for case report**

<table>
<thead>
<tr>
<th></th>
<th>Oswestry Disability Index</th>
<th>Global rating of change scale</th>
<th>Global rating of function</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial</strong></td>
<td>10%</td>
<td>N/A</td>
<td>90%</td>
</tr>
<tr>
<td><strong>Follow up (12 weeks later)</strong></td>
<td>2%</td>
<td>+7</td>
<td>100%</td>
</tr>
<tr>
<td><strong>N/A</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

N/A=not applicable
block in the development of clinical reasoning skills. Expert clinicians regularly use pattern recognition for common patient problems and hypothetico-deductive reasoning for complex problems. Expert clinical reasoning and differential diagnosis is an evolving process that involves identifying working interpretations and repeated hypothesis generation. Deletion and refinement of these interpretations and hypotheses allows health professionals to develop an understanding of patient problems. A refinement of these skills with reflective thinking leads to achieving the primary goal of identifying the patient’s clinical presentation and matching it with the most effective treatment approach.

In this case, pattern recognition suggested pain generation from the lumbar spine or pelvis, which was not reproduced with clinical examination. Reflective thinking led to employing further sensitive testing to the neural system. Sensitizing maneuvers, as described by Butler, are used during neural tissue provocation tests and can assist clinicians in differentiating between non-neural and neural tension related to musculoskeletal pathologies. Sensitizing maneuvers helped to rule in adverse neural tension but not before efficiently ruling out other musculoskeletal sources of pain.

Neural tissue is able to tolerate mechanical forces generated during movements associated with every day and sport activities. Peripheral neuropathic pain is a term that is used to describe what occurs when nerve roots or peripheral nerve trunks have been injured by mechanical or chemical stimuli. Peripheral neuropathic mechanisms can present similarly to other common musculoskeletal syndromes, such as lateral epicondylgia, achilles tendinosis, heel pain, inversion ankle sprains, and hamstring tendinosis.

Interventions for this patient were selected in order to address his concordant sign and functional limitations found during the initial evaluation. The use of tensioning neurodynamic exercise was the focus of the treatment. Currently, there is limited evidence to support the use of neural mobilization in patients presenting with adverse neural tension, or even pathology in general. Low quality studies have demonstrated that a treatment focusing on movement of neural tissue can be safely implemented to promote recovery for patients with peripheral neuropathic pain. This case report discusses patient education regarding neural mechanics and their role in the patient’s pathology was imperative in order to improve compliance to the home exercise program.

While it might be argued that the patient initially had limited disability, and may have improved on his own, one independently guided treatment was both objectively and anecdotally successful. As demonstrated through subjective reports of improvement, decreasing pain levels (MCID of 2), improved ODI (MCID of 30% from baseline score), maximum improvement on GROC score (+7), and a return to pain free running, this patient responded well to the selected treatments. Additionally, these significant results were after six months of symptoms that had not improved on their own and the patient continued to be significantly improved 12 weeks after intervention.

Limitations of the case report include lack of any type of functional testing, a formal running assessment, knee examination, and objective assessment during the follow up visit. At the follow up visit the plan was to evaluate running mechanics and perform further functional testing but the patient presented to the visit without running attire, reporting satisfaction with his outcomes at that time. High-level patient satisfaction has been shown with optimizing aspects of the patient-therapist interaction, the process of care, and performing a well-organized evaluation and treatment.

**Conclusion**

Ascertaining the pain generator in complex patient presentations requires a diligent, systematic examination approach based on replication of the patients concordant pain. The development of differential diagnosis and clinical reasoning skills is important. Improving clinical reasoning skills requires deliberate practice and routinely engaging in reflective thinking before, during, and after each patient interaction. This case report is a description of utilizing the reasoning process in attempts of providing optimal outcomes in a patient.

**REFERENCES**


ABSTRACT

Background and Purpose: Lateral thigh pain, commonly referred to as greater trochanteric pain syndrome (GTPS) and/or iliotibial band syndrome (ITBS) is commonly treated by the physical therapist. Lateral thigh pain is commonly treated by the physical therapist. The sources of lateral thigh pain are commonly attributed to GTPS and/or ITBS though various pathologies may contribute to this pain, of which trigger points (TrPs) may be an etiology. Dry needling (DN) is an intervention utilized by physical therapists where a monofilament needle is inserted into soft tissue in order to reduce pain to improve range of motion/motor control dysfunction. This can assist with facilitation of return to prior level of function. The purpose of this case report is to report the outcomes of a patient with lateral hip and thigh pain treated with DN as a primary intervention strategy.

Case Description: The subject was an active 78-year-old female recreational walker who was referred to physical therapy for chronic left lateral hip and thigh pain of greater than one-year duration without a clear mechanism of injury. She had a history of previous physical therapy treatment for the same condition, and previous therapeutic intervention strategies were effective for approximately two to three months duration prior to return of pain symptoms. Physical examination supported a diagnosis of GTPS/ITBS. Subjective reports denoted sleep deficit due to pain lying on the left side at night and difficulty walking more than five minutes. Objective findings included decreased strength of the hip musculature and reproduction of pain symptoms upon flat palpation in specific locations throughout the lateral hip and thigh regions. She was treated for eight weeks using only DN to determine the effectiveness of DN as a primary intervention strategy, as previous physical therapy interventions were inconsistent and were only beneficial in the short-term.

Outcomes: Clinically meaningful improvements were noted in disability and pain, as measured by the Lower Extremity Functional Scale and Quadruple Visual Analog Scale. Improvement in strength was not an objective measure being assessed, however, lower extremity strength improvement was noted upon final physical examination. This case report focused on pain reduction for improved function rather than strength improvement. Improvements in pain and disability were subjectively reported. The subject was able to lie on her left side at night, which improved her ability to sleep. She was also able to tolerate walking approximately twenty to thirty minutes for improved community ambulation needs.

Discussion: This case report presents promising outcomes for the use of DN in the treatment of chronic lateral hip and thigh pain. Further research is recommended to determine if DN is clinically beneficial independent of other therapeutic interventions such as exercise, myofascial release/massage, non-thrust mobilization, or manipulation.

Level of evidence: Level 4

Key words: Dry needling; hip pain; iliotibial band; trochanteric bursitis

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INTRODUCTION

Lateral hip and thigh pain may be the result of a host of pathological etiologies including, but not limited to osteoarthritis of the hip joint, greater trochanteric bursitis, iliotibial band syndrome (ITBS)/snapping hip syndrome, muscle weakness/strength imbalances, flexibility deficits, spinal pathology, and leg length discrepancies.1-15 “Trochanteric bursitis” (TB) is still common terminology used to identify lateral hip pain by medical providers. TB tends to occur between the fourth and sixth decades of life, though cases have been reported in all age-groups.11 Trochanteric pain syndrome was originally thought to be caused by inflammation of the sub-gluteus maximus bursa (i.e. bursitis), but recent MRI and ultrasound studies question the idea that bursitis is the primary source of trochanteric pain.13 A contemporary term, greater trochanteric pain syndrome (GTPS) encompasses a number of disorders of the lateral, peri-trochanteric region of the hip, including trochanteric bursitis, tears of the gluteus medius and minimus and external coxa saltans (snapping hip).14 The incidence of GTPS is reported to be approximately 1.8 subjects per 1000 per year, with the prevalence being higher in women, and subjects with concomitant low back pain, osteoarthritis, ITB tenderness, and obesity.15 Symptoms consist of persistent pain in the lateral hip radiating distally down the lateral thigh to the knee, and occasionally below the knee and/or buttock. Physical examination typically indicates point tenderness in the posterolateral area of the greater trochanter.15

Iliotibial band (ITB) involvement, which is typically associated with lateral knee pain, is regularly observed concurrently with GTPS from a clinical perspective. From a diagnostic standpoint, the lateral knee is the most extensively researched region of ITB pain pathology, but clinically it is common to have palpable tenderness along the entire length of the ITB. There is a paucity of evidence supporting the effectiveness of treatment strategies for ITBS, which include non-steroidal anti-inflammatory drug (NSAID) administration, phonophoresis, corticosteroid injections, deep friction massage, and correction of hip strength abnormalities.4,5 The inconsistency with accurate diagnosis of chronic lateral hip and thigh pain sources leads to the possibility of TrPs in the affected hip and thigh musculature as being sources of pain.

Dry needling (DN) research continues to be in spotlight in the therapy community regarding validity/effectiveness as a treatment strategy for a host of pathological conditions. Currently, no randomized control trial (RCT) studies have looked at the effectiveness of DN to the lateral hip and thigh for pain reduction. Various continuous education programs teach DN techniques, and some of the programs focus on trigger points (TrPs) as the primary justification for using DN intervention. TrPs have been studied extensively over the years as sources of pain,16-28 and the literature suggests a TrP is identified clinically by palpation of a tender nodule in a taught band of muscle and subject pain recognition of tender spot palpation.28 However, accurate diagnosis of TrP location is difficult due to the lack of a clinician’s ability to reliably and repeatably identify a specific TrP.15,19,20,21,28 Two studies, one by Sciotti et al23 and one by Myburgh et al22 have shown positive inter-rater reliability for identification TrPs in the upper trapezius muscle if the examiners are experienced, however, pairing experienced and inexperienced examiners caused a reduction in the ability to reliably identify TrPs.22

In regards to DN for intervention related to TrPs, some authors such as Hong et al29 suggest that the local twitch response (LTR) is necessary for maximum effectiveness of trigger point dry needling (TrP-DN), however, Tough et al28 indicate that of the original four criteria most commonly used to diagnose TrPs (LTR, predicted pain referral pattern, palpable tender nodule in a taught band of tissue, and reproduction of pain symptoms), LTR and predicted pain referral pattern are no longer considered essential for diagnosis. It should be noted that DN is not limited to myofascial intervention, although this case report’s DN intervention was focused on treating myofascial TrPs in the local tissue.

Physical Therapists regularly attempt to determine the “why” of the root cause of pathology and how to “fix” the issue. Due to the already noted lack of research supporting diagnostic criterion and treatment strategies for lateral hip and thigh pain, the need for clinically effective intervention tools that can quickly improve pain, thereby improving general function that has become deficient due to chronic pain are necessary. The purpose of this case
report is to determine the effectiveness of DN as a primary treatment strategy in a subject with chronic lateral hip and thigh pain. Informed consent was obtained from the patient prospectively prior to the start of intervention.

CASE DESCRIPTION
The subject in this study was an active 78-year-old female recreational walker, who was referred to physical therapy for evaluation of chronic non-specific left lateral hip and thigh pain. The reports of pain affected her ability to negotiate stairs, walk for exercise and shopping needs, and also affected her sleeping patterns. She was treated a few years previously using "traditional" physical therapy interventions including exercise, neuromuscular re-education techniques, deep friction tissue mobilization, and ultrasound. This provided temporary relief, but it was not immediate and her pain persisted (intermittently) over the years. Intermittent symptoms consistent with radiculopathy were reported. The reported radicular symptoms had been occurring for years and positional changes such as sitting down/laying down always eliminated her pain immediately. She did not report regular bouts of radicular symptoms affecting her daily function. Her overall general health was good, though she reported having a pacemaker. The patient was assessed and cleared of contraindications to the use of DN. Given the fact she had a pacemaker; the use of electro-stimulation was not utilized as an addition to DN in this case report. She was already taking anti-inflammatory medication on an as needed basis for hip pain and she had received a cortisone injection six weeks prior to presentation to the clinic, which was reported to only reduce pain for a very short period. Her goal was to reduce pain to improve her ability to walk, sit, sleep, and travel.

The outcome measures employed in this case report were the Lower Extremity Functional Scale (LEFS) and the Quadruple Visual Analog Scale (QVAS) and are reported in Table 1. Upon initial evaluation per the QVAS, the subject reported her current (28 mm), average (35 mm), best (12 mm), and worst (90 mm) pain levels during the last 24-hour period. The visual analog scale (VAS) has moderate to good reliability (correlation coefficient 0.60-0.77) to detect disability and high reliability for pain (correlation coefficient 0.76-0.84). The minimum clinically significant change has been estimated to be 11 points (mm) on a 100 point (mm) scale.

The LEFS was used to assess functional disability. The LEFS is a patient reported functional tool that can be easily and quickly completed and has been found to be a reliable and sensitive to change when compared to the SF-36 with a minimal detectable change being 9 scale points and the minimal clinically important difference being 9 scale points. Test-retest reliability per Watson et al was found to be high for subjects with anterior knee pain, and Yeung et al reported a large responsiveness to change as well as good reliability and validity in outpatient and inpatient orthopedic settings among subjects with revision joint replacements. The results of the LEFS are also shown in Table 1, and the subject had a baseline score of 24/80.

EXAMINATION
The subject in this case report was treated several years previously by the author. At that point, she was treated with exercise, myofascial release and deep tissue mobilization techniques, and ultrasound for the same issue. She improved gradually during that intervention period, but her pain returned relatively quickly (approximately 2-3 months). She presented

<table>
<thead>
<tr>
<th>Table 1. Outcome measures</th>
<th>Initial Exam</th>
<th>Upon Completion at 8 Weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEFS</td>
<td>24/80</td>
<td>59/80</td>
</tr>
<tr>
<td>QVAS Current</td>
<td>28 mm</td>
<td>13 mm</td>
</tr>
<tr>
<td>QVAS Average</td>
<td>35 mm</td>
<td>20 mm</td>
</tr>
<tr>
<td>QVAS Best</td>
<td>12 mm</td>
<td>6 mm</td>
</tr>
<tr>
<td>QVAS Worst</td>
<td>90 mm</td>
<td>82 mm</td>
</tr>
</tbody>
</table>

LEFS: Lower Extremity Functional Scale
QVAS: Quadruple Visual Analog Scale for pain.
for this episode of care with reports of burning pain in the left lateral hip and thigh from the superior iliac crest region to the proximal lateral knee, and from the tensor fascia latae (TFL) region to the posterior superior iliac spine (PSIS) and lateral piriformis area of the hip and thigh. Pain increased with lying, sitting, standing, and walking.

She had a history of low back pain, and a previous radiographic study showed lumbar arthritic changes at the L3 through S1 levels. Given her history of back pain, it was necessary to rule out lumbar radiculopathy, pain of spinal origin, and sacroiliac joint (SIJ) involvement (given the SIJ is innervated from branches of L3-S4). She reported intermittent left lower extremity radicular-like symptoms, but this was a minor secondary issue that had no current impact on her daily laying, sitting, standing, and walking tolerance. She had an observable minimally shorter left lower extremity in standing, which, in the opinion of the author, could have been an issue affecting mechanical changes to gait patterns leading to the reported pain over the years. Based the subject’s subjective reports including her previous history, differential diagnoses included pain of discogenic origin, osteoarthritis of the hip, sacroiliac joint dysfunction, and GTPS/ITBS.

Assessment of posture and gait mechanics was performed. This included assessment of lumbar, innominate, and global spinal positioning, and observation of gait mechanics. Physical examination revealed observable mild loss of lumbar lordosis, but given the layers of tissue covering the lumbar region including increased adiposity, accurate palpation and observation of lumbar spinal curvature was difficult and unreliable. There was observed rounded bilateral shoulder positioning. The left innominate was slightly inferior and asymmetric compared to the right upon observation. It is noted that the ability to properly assess pelvic symmetry with static or movement-based positioning testing, including leg length discrepancy, is not valid or reliable, therefore palpation assessment for positional faults of the SIJ were not performed. She limped on the left lower extremity and demonstrated a very mild Trendelenberg walking pattern indicating left hip abductor muscle weakness. No other postural abnormalities were noted.

Bilateral lower extremity (BLE) strength was assessed via manual muscle testing (MMT) in a short sitting position with her hips and knees flexed and the legs hanging off the table. The results are shown in Table 1. Note that hip flexion (4+/5 bilateral), abduction (4/5 bilateral), and knee flexion (4/5 bilateral) weakness bilaterally was noted upon initial presentation. All other BLE MMT scores were 5/5 bilaterally.

A lower quarter neurological examination was performed to screen for symptoms of spinal origin. Dermatomal testing was normal for light touch sensory assessment of the T10-S2 dermatomal regions of the trunk and lower extremities. Myotomal testing was assessed via MMT of the same nerve root levels, see results above. DTRs were assessed via testing of the L4 and S1 nerve roots in short sitting with the legs off the table and using a reflex hammer at the patellar tendon and Achilles tendon bilaterally. Patellar tendon reflex was 2+ and Achilles tendon reflex was 0 bilaterally. Lack of Achilles DTR could be attributed to chronic and intermittent radicular symptoms stemming from the L5-S1 nerve root level, though no diagnostic images looking in detail at the nerve roots had been performed at the time of the intervention. Seated slump testing (sensitivity = 0.84; specificity = 0.83) was performed to assess for lumbar disc herniation at the L4-S1 levels, and this did not show pathological involvement. There were no neurovascular abnormalities noted.

Symptom centralization testing for discogenic origin has been found to be valid and reliable. The subject was tested via repeated flexion and extension movements in standing for peripheralization/centralization phenomenon, which was negative for discogenic pain. Sacroiliac joint involvement was ruled out using a multi-test regimen as indicated by Van der Wurff et al and the Active Straight Leg Raise (ASLR) as described by Mens et al. Van der Wurff et al included five special tests in the multi-test regimen: Distraction test, Compression test, Thigh Trust test, Patrick sign, and Gaenslen’s test. All testing of the SIJ was negative.

Palpation assessment revealed tender nodules in taut tissue bands in the gluteus medius, gluteus maximus, lateral piriformis, greater trochanteric region, and ITB regions of the left LE, indicative of the likelihood of TrPs in the affected musculature. Pain from this region likely caused her functional
mobility deficit, as pain was the limiting factor in her intolerance to walking activities. There were no autonomic responses noted (e.g. temperature change, diaphoresis, etc.) and sensation was intact to light touch and deep pressure. Trophic changes of the skin were also absent.

EVALUATION/ DIAGNOSIS
Upon completion of subjective history and physical examination, TrPs in the aforementioned musculature were suspected as the underlying pathology causing pain. Strength deficit in the hip musculature and observable asymmetric innominate positioning were present and could possibly have contributed to the long term cause of the subject's lateral hip and thigh pain. As mentioned prior, the ability to definitively ascertain reliable innominate positioning by palpation is poor; therefore the therapist could not reliably say that pain was due to improper pelvic symmetry. This leads to the likelihood of the possibility of TrPs as a source of pain. This decision was based upon the author's three years of clinical experience utilizing DN for muscular pathology.

Clinical reasoning determined DN should be the intervention employed, due to the palpable taut bands and reported pain reproduction. Due to the subject's reports of severe pain upon presentation, it was not believed that stretching and exercise interventions would provide the pain relief she was seeking.

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 muscle soreness, bruising, and vasovagal reaction. More serious (but rare) complications include infection, broken needle, and pneumothorax.43 There were no reported contraindications to the use of DN. Contraindications include, but are not limited to: local infection, recent cancer/ history of immune suppression, bleeding disorders, current/ chronic use of anti-coagulant medications, pregnancy, compromised sterility of equipment, and lack of practitioner practical knowledge.43

The subject was treated for sixteen total sessions, two- times per week for eight weeks. She was positioned in right side lying with a pillow between her knees on a hi-low table for subject and therapist comfort and to reduce the effects of vasovagal response. The following soft tissues were treated: gluteus maximus and medius, lateral piriformis, greater trochanteric bursa area, and four points on the lateral thigh (ITB/ vastus lateralis). These points are outlined in the following paragraphs.

The needles used for treatment of this subject were solid monofilament Seirin J-type sterile needles, No. 5 (0.25 diameter) x 30 mm. in length; No. 8 (0.30 diameter) x 60 mm.; and No. 8 (0.30 diameter) x 50 mm. Needles were used one time and discarded, as the risk of needle injury to the therapist is increased with techniques that teach “re-sheathing” of the needles to use in other locations on the same subject.43 Each needle was held in the therapist's dominant hand for application of and manipulation of the needle within the tissue. Prior to insertion of the needles, an application of 70% isopropyl alcohol was performed to cleanse the treatment areas.

DN to the gluteus maximus and medius points were performed with 50 mm length needles. The needles were inserted into tender nodules in the tissue identified upon flat palpation, which were located three-fingerbreadths distal to the mid iliac crest (Figure 1) and three fingerbreadths lateral to the PSIS (Figure 2). The

Figure 1. Needle placement for gluteus maximus
The efficacy of DN intervention was measured by reduction of pain and disability levels, objective hip strength, subjective reports of improvement in the subject's overall functional ability, and quality of life. Initially and eight weeks after the initial treatment session, pain and disability was assessed via the LEFS and QVAS outcome measures. Hip strength was assessed via MMT in sitting, as previously described.
The QV AS (average) improved from 35 mm to 20 mm and QV AS (best) improved from 12 mm to 6 mm. The QV AS (current) significantly improved from 28 mm to 13 mm, and the QV AS (worst) improved from 90 mm to 82 mm. The QV AS (average) and QV AS (current) both met the clinically meaningful change threshold, but the QV AS (best) and QV AS (worst) did not meet the clinically meaningful change threshold.

Table 2 shows objective results including BLE strength. The primary intent of this case report was not to attempt to directly address strength; rather it was to focus on reduction of pain. The improvements in strength that were noted with the use of DN were not expected, however, strength improvements were demonstrated, including hip flexion MMT improvement from 4-/5 to 4/5 bilaterally, hip abduction MMT improvement from 4/5 to 5/5 bilaterally, and knee flexion MMT improvement from 4/5 to 5/5 bilaterally. The subject, upon completion of the eight-week intervention period, also subjectively reported improved ambulation tolerance, sleep, and improved ability to sit and stand throughout the day.

DISCUSSION

The subject reported significant improvement of the initial hip and thigh regional pain she came to have addressed. The LEFS and QVAS sub groups for average and current pain showed clinically significant improvements, though her “best” and “worst” pain did not show clinically meaningful improvement per the 11-point threshold of the VAS. She subjectively reported being able to sleep, walk without limping, and sit and stand for extended periods, which she could not tolerate prior to the intervention. She continued to have pain, and DN did not eliminate her pain symptoms, but clinical meaningful improvements were demonstrated. Strength in the hip flexors, abductors, and knee flexors improved bilaterally. Although this case report was not specifically intended to assess improvement in strength as an outcome, it is hypothesized that the improvements noted were likely due to reduced pain causing reduction of poor gait mechanics, improving her ability to tolerate walking. This in turn, may have allowed her strength to normalize. Again, this is a clinical hypothesis without evidence of support. The findings of this case report preliminarily support the use
of DN as an initial intervention strategy for reduction of pain related to chronic lateral hip and thigh pain in order to improve functional disability. This initial intervention strategy may then allow the therapist to employ other intervention strategies focused on strength, posture, home exercise programming/subject education for longer term relief of this condition.

This case report uses only a single subject, as is typical of a case report. This is an inherent limitation offering only results that relate to this single subject that cannot be generalized to larger populations. 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 strategy for GTPS and/or ITB etiologies. Longer assessment periods looking at long-term benefit versus immediate or short-term benefit also need to be assessed, as this case report showed immediate and short-term (two month) improvements in pain and disability, but did not assess longer-term outcomes. 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 and massage or non-thrust mobilization.

CONCLUSIONS
DN of the lateral hip and thigh was tolerated well by this subject, who demonstrated improvements in pain and function without adverse effects. Given her reduction in pain and improvements in reported function, the use of DN for chronic lateral hip and thigh pain etiologies shows promise. Future research is needed to determine the full effectiveness of DN for lateral hip and thigh pain, as well as, to determine longer-term outcomes.

REFERENCES


38. Robinson HS, Brox JI, Robinson R, Bjelland E, Solem S, Telje T. The reliability of selected motion- and


ABSTRACT

Purpose/Background: Despite recent advances in anterior cruciate ligament reconstruction (ACL) surgical techniques, an improved understanding of the ACL's biomechanical role, and expanding research on optimal rehabilitation practices in ACL-reconstructed (ACLR) patients, the re-tear rate remains alarmingly high and athletic performance deficits persist after completion of the rehabilitation course in a large percentage of patients. Significant deficits may persist in strength, muscular activation, power, postural stability, lower extremity mechanics, and psychological preparedness. Many patients may continue to demonstrate altered movement mechanics associated with increased injury risk. The purpose of this clinical commentary and literature review is to provide a summary of current evidence to assist the rehabilitation professional in recognizing, assessing, and addressing factors which may have been previously underappreciated or unrecognized as having significant influence on ACLR rehabilitation outcomes.

Methods: A literature review was completed using PubMed, Medline, and Cochrane Database with results limited to peer-reviewed articles published in English. 136 articles were reviewed and included in this commentary.

Conclusions: Barriers to successful return to previous level of activity following ACLR are multifactorial. Recent research suggests that changes to the neuromuscular system, movement mechanics, psychological preparedness, and motor learning deficits may be important considerations during late stage rehabilitation.

Level of evidence: Level 5- Clinical Commentary

Key words: Anterior Cruciate Ligament (ACL), biomechanics, exercise, injury prevention, knee,
INTRODUCTION
ACL injuries account for up to 50% of all sustained knee injuries with an estimated frequency of 6.5 ACL injuries per 10,000 athletic exposures and an estimated one billion dollars spent annually on ACLR in the United States.1,2 Approximately 90% of patients who seek treatment for an ACL tear undergo surgical reconstruction.3 For many of these patients, the goal is return to sport or recreational activities at their pre-injury level. Recent evidence suggests that the outcome rates for return to sport and continued participation after return are lower than desired.4-8 Ardern et al reported return to sport rates at 12 months after ACLR ranged from 33% to 92%.4 Multiple authors report rates of re-tear or secondary injury to the uninjured lower extremity following return to high level activity ranging from four to thirty three percent.9-15 Paterno et al reported results indicating that roughly one-third of female high school athletes suffer an injury to the contralateral lower extremity within two years of return to sport following ACLR.9 Myer et al demonstrated that resolution of specific functional deficits following ACLR was not associated with time from surgery.10 This suggests that athletes may require longer time frames to restore acceptable levels of functional performance than currently recommended. These results may also suggest shortcomings in commonly utilized postoperative rehabilitation protocols and return to sport testing criteria. Many of these protocols have focused on biomechanical and musculoskeletal factors such as knee range of motion, lower extremity strength, measures of ability to produce power as compared to the uninjured side, and graft laxity to determine readiness for rehabilitation advancement and return to previous level of activity. The purpose of this clinical commentary and literature review is to provide a summary of current evidence to assist the rehabilitation professional in recognizing, assessing, and addressing factors which may have been previously underappreciated or unrecognized as having significant influence on ACLR rehabilitation outcomes. Evidence for the potential influence of pain, psychological variables, and neurological impact of ACL injury and ACL reconstruction will be examined. Optimal strategies to enhance motor learning, restore movement quality and minimize secondary injury risk will be discussed. The current criteria for return to sport decision making and traditional guidelines will be addressed,10 and updated considerations and emerging evidence for newer methods of assessment and interventions in late stage ACLR rehabilitation will be reviewed.

MOVEMENT ALTERATIONS AND INJURY RISK
Actual reported re-injury rates range from 1 in 4 to 1 in 17 in ACLR patients,11-14 with a higher incidence reported in the first two years post-injury.15 Multiple authors have identified altered biomechanics and movement patterns in male and female ACL-reconstructed patients when comparing the involved limb to the uninjured.16-25 Altered lower extremity biomechanics have also been discovered when comparing patients with ACL injuries to uninjured control subjects.26 These movement alterations have been identified during multiple sport-specific maneuvers including single leg jumping,16,17 sagittal double leg jumping and landings,18-21 lateral hopping,22 side-step cutting,23,24 and jogging.25 Movement alterations may persist for time frames ranging from six months to beyond two years post-operatively, even in some athletes cleared to return to full participation in sport.18,21 Paterno et al examined factors that predicted second ACL injury risk in ACLR patients prospectively.11 These authors identified four factors including increased knee valgus, asymmetry in internal knee extensor moment at initial contact, single leg postural stability, and opposite hip rotation moment as significant predictors of re-injury risk. It has also been demonstrated that specific targeted neuromuscular training can improve one or more of these identified risk factors.27,28 Recently, Goerger et al were able to examine dominant limb biomechanics in a group of subjects both pre-ACL injury and after subsequent surgical reconstruction.26 Their findings indicated that ACL injury resulted in altered movement patterns in both the involved and uninjured lower extremities, similar to those demonstrated to be predictive of lower extremity injury. These altered movement patterns did not resolve following ACLR and subsequent rehabilitation. This suggests that changes to the traditional ACLR rehabilitation paradigm may be necessary, particularly with return to sport training and timeframes for sport clearance. It is imperative that
the rehabilitation professional appreciate the biomechanical and musculoskeletal issues that may result from ACL injury as well as the potential effects on higher levels of the neuromuscular system. Targeted interventions to improve movement quality during high level sport specific tasks may need to be further explored and refined in order to lower re-tear and secondary injury rates.

NEUROLOGICAL EFFECTS OF ACL INJURY

The effects of ACL injury on joint stability, lower extremity biomechanics, and isolated muscle group performance have been documented in the medical literature. Research examining the potentially detrimental neuroplastic effects of ACL injury and subsequent surgical reconstruction is much less plentiful in spite of the potential effect on function and preparedness for return to sport.

Disruption of the native ACL leads to mechanical instability of the knee, but also can alter neuromuscular control due to disruption of mechanoreceptors within the ligament. Disruption of these mechanoreceptors alters somatosensory signals and decreases the afferent input to the central nervous system (CNS). The resultant decrease in joint position sense and kinesthesia, along with increased nociceptor activity associated with pain and effusion potentially impairs motor control. Kapreli et al concluded that ACL injury can cause reorganization of the CNS and result in changes in activation patterns of sensorimotor cortical areas as compared to matched controls with intact ACL. These changes in neurophysiologic function are not corrected with ACLR, as the afferent pathway from the mechanoreceptors present in the native ACL cannot be reliably restored. This concept is further supported by the work of Baumeister et al in a study comparing cortical activity during knee joint angle reproduction tasks in ACLR patients and matched controls. The authors found significantly higher levels of cortical activity during movement tasks in knees status post ACLR as compared to non-injured knees. Grooms et al suggested that the decreased somatosensory input available following ACL injury requires the patient to rely on visual feedback and increased conscious cortical involvement in order to effectively regulate neuromuscular control. Grooms et al further suggested that the visual feedback and conscious motor planning mechanisms may be efficient during simple or predictable tasks but may become overwhelmed and less efficient in the complex athletic environment leading to increased injury risk. This information suggests that the traditional rehabilitation model focused on restoration of range of motion, muscle strength and endurance, and enhanced biomechanical function during varying levels of dynamic tasks may fall short when attempting to minimize re-injury risk. Further investigation of rehabilitation techniques that could be utilized to impact the changes in neuroplasticity and motor control may be necessary to improve outcomes following ACLR.

PAIN

Recent research also appears to support the idea that pain may alter neuromuscular function and trigger adaptations that could result in detrimental effects on long term health and physical performance. Hodges and Tucker proposed that pain may trigger neuromuscular changes due to the intent to protect the injured region of the body and minimize the experience of pain. They proposed that these adaptations may include: redistribution of activity within or between muscles and changes in mechanical behavior including stiffness or modified movement patterns. They suggested that these changes occur at multiple levels of the nervous system and may be additive, complementary, or competitive. While these changes may provide the intended benefit of short term relief of pain, they may also result in decreased movement range, decreased movement variability, and increased load in specific regions of the knee joint. This may have long term implications on knee health, re-injury risk, and athletic performance. It is not currently clear whether these adaptations are a result of pain suffered at the time of initial ACL injury, post-operative pain, or the summative effects of both.

In support of this theory, Tucker et al found that motor unit discharge of the quadriceps was negatively affected not only by the presence of pain, but also the anticipation of pain. More importantly, changes in motor unit discharge continued regardless of whether pain was present or not. Hug et al found inter-muscular changes in response to pain within the quadriceps muscle group suggesting adaptive differences that could be attributable to
changes in role or function of individual muscles or neurophysiological differences or constraints. These changes may have significant rehabilitation implications in an ACLR population.

**ALTERATIONS IN SPECIFIC MUSCLE FUNCTION**

Pain and other factors may hinder optimal knee and lower extremity muscular performance in an ACLR population. Thomas et al found that residual weakness persisted post-operatively in the knee extensors and knee flexors of ACLR subjects, while hip extensors, hip adductors, and ankle plantar flexors fully recovered to preoperative levels. These authors did not evaluate the effect of ACLR on strength in hip abductors and hip external rotators.

Multiple authors have identified weakness in the hip and core muscle groups as a predictor of lower extremity injury risk. Proximal lower extremity muscle function has demonstrated a significant effect on lower extremity mechanics and weakness in these groups have been identified in other common lower extremity pathologies including patellofemoral pain syndrome, iliotibial band syndrome, and ankle sprain. The link between proximal hip weakness and lower extremity pathology supports the concept of regional interdependence.

Core musculature strength has not been well studied in regards to an ACLR population, however, deficits in core proprioception and neuromuscular control have been found to be predictive of knee injury risk. Noehren et al examined female athletes who had undergone ACLR and did not find differences in hip abduction or external rotation strength, but did find significant differences in trunk neuromuscular control when compared to healthy, uninjured subjects. There are few current studies that have examined changes in hip and core muscle activation patterns in the presence of ACL injury or resultant surgical reconstruction. It is possible that selective proximal hip and core weakness or activation differences may be present pre and/or post-ACLR and may have an influence on movement mechanics and function.

Return of hamstring strength and torque following ACLR has been largely studied with respect to hamstring graft harvest and subsequent tendon regeneration and morphology. Multiple studies have identified hamstring weakness following ACLR, specifically at higher knee flexion angles. However, few studies have examined potential neuromotor influence on hamstring weakness and activation following ACLR. Ristanis et al identified an electromechanical delay in hamstring activation following ACLR with hamstring graft harvest. Briem et al demonstrated altered inter-limb hamstring activation patterns that also differed from healthy controls. ACLR subjects who had a hamstring graft demonstrated increased lateral hamstring activity versus medial hamstring activity. Arnason et al also found significant alterations in lateral and medial hamstring activation between lower extremities in ACLR subjects with hamstring autograft during hamstring exercise. Increased medial hamstring activity may limit knee valgus and subsequent ACL loading. Zebis et al demonstrated that decreased semitendinosus pre-activation with cutting was a predictor for increased risk of noncontact ACL injury. The alterations in hamstrings neuromotor activity have been shown to contribute to modified lower extremity mechanics in ACLR subjects. Targeted neuromuscular training is able to modify medial hamstring activity, and subsequently may impact knee valgus positioning during sport activity.

Extensive research has examined influence of ACLR on quadriceps function. Multiple studies have identified persistent knee extensor or quadriceps muscle weakness and/or activation deficits in early and late postoperative periods. In the early postoperative period, increased knee effusion is often present and has been shown to cause quadriceps inhibition along with changes in afferent feedback. Lynch et al recently determined that knee effusion did not directly mediate quadriceps inhibition after initial ACL injury. They determined that arthrogenic muscle inhibition was present at the quadriceps bilaterally after ACL injury and theorized that pain, inflammation, and or inactivity may contribute to these deficits. These bilateral activation deficits are suggestive of more complex central nervous system involvement versus locally mediated neurologic responses at the knee.

Recently several authors have suggested that neuromotor deficits occur at higher central nervous system levels in ACLR patients. Changes in quadriceps
muscle mechanics and subsequent weakness were observed after ACLR versus the uninvolved lower extremity suggesting changes at a local quadriceps muscular level, but possibly also at a neuromotor level.79 These changes included decreased strength at more lengthened positions in higher knee flexion angles and at slower speeds with isokinetic and isometric testing.79 Kuenze et al found that ACLR patients demonstrated significant deficits in cortical excitability, quadriceps strength, and quadriceps activation in the surgical limb when compared to both the uninvolved limb and matched healthy controls.80 These cortical excitability deficits persisted beyond six months post-operatively and extended into the return to recreational activity. In a similar study, Lepley et al determined that decreased spinal-reflexive and corticospinal excitability was present preoperatively, two weeks post-operatively, and six months post-operatively.72 These studies documented bilateral quadriceps weakness and activation deficits, including decreased central activation ratio.80 Bilateral deficits in central activation ratio in ACLR subjects has also been linked to poor return of quadriceps activation and strength.81 It appears that current published ACLR rehabilitation model paradigms are not adequately addressing these neuromotor deficits based on current research. Tracking values such as central activation ratio may provide a more valuable future estimation of return of strength and activation to assist in return to sports decision-making and rehabilitation progressions for ACLR athletes. Recently, Kuenze et al studied these values and determined that quadriceps central activation ratio above 89.3% was the strongest unilateral indicator at the involved leg of healthy-knee related outcomes determined by pain, knee-related function, and physical activity level.82 Schmitt et al demonstrated quadriceps index (QI) of less than 85% in comparison to the uninvolved lower extremity in ACLR subjects was predictive of poor functional hop test performance while scores greater than 90% were comparable to uninjured subjects.83 Similarly Schmitt et al found that quadriceps weakness (QI < 85%) was related to altered lower extremity landing mechanics and forces, while ACLR subjects with QI > 90% demonstrated mechanics similar to uninjured subjects.84 The group with QI < 85% demonstrated increased peak vertical ground reaction force and peak loading rate at the uninvolved limb.84 The profound effect on landing mechanics is significant given the evidence linking alterations in movement mechanics in ACLR patients to re-injury risk, performance deficits, and increases in joint reactive forces.26

Rate of force development has been characterized as a measure of explosive muscle action and neural drive.85 Reduced rate of force development of specific muscles following ACLR may have similar effects on athletic performance as muscle weakness. Angelozzi et al found that at six months after ACLR maximum voluntary isometric contraction levels in the involved limb had returned to 97% of preinjury values.85 However, decreased rate of force development persisted at the affected lower extremity and did not near preinjury levels until twelve months post-operatively. Knezevic et al also found deficits in rate of force development and maximal strength at the quadriceps and hamstrings between the involved and the uninvolved lower extremity in ACLR subjects at six months post-operatively.86 The rate of force development is an important factor in athletics due to the need to accelerate, decelerate, and change direction. For this reason, the results of these studies have potentially significant implications in return to sport time frames and overall athletic performance. The authors of these studies did not offer a hypothesis for the continued deficits in rate of force development, but their results suggest that neuromuscular function of the involved lower extremity may remain impaired well into the late post-operative rehabilitation course.

FATIGUE
In addition to changes in neuromuscular activation, multiple studies have identified the detrimental effects of fatigue on the involved and/or uninvolved lower extremity.87-91 Fatigue has been reported to have a negative effect on postural stability, neuromuscular control, and lower extremity mechanics during sport activity or components of sport performance in ACLR subjects.91-94 Deficits in postural stability, increased knee valgus, and increased opposite hip internal rotation moment of the lower extremity are correlated to increased ACL re-injury risk.11 McLean and Samorezov noted a crossover effect on
lower extremity mechanics from the involved lower extremity to uninvolved contralateral lower extremity after a fatigue protocol. Decreased knee flexion angle at initial contact was observed, as well as increased knee abduction and hip internal rotation at peak stance during single leg jumps. The crossover effect on the uninvolved lower extremity may have added significance given the results of a recent study which found a twenty percent injury rate in females who had undergone ACLR the contralateral lower extremity. This crossover effect also reinforces the concept of higher level central nervous system control and processing of lower extremity mechanics, which as noted previously appear to be impacted by ACL injury and/or reconstruction.

The effects of fatigue may be more pronounced in ACLR subjects. Fatigue should be considered in late stage rehabilitation program design to ensure that ACLR subjects are able to maintain consistent movement mechanics under fatigued conditions. Exercise dosage and training intensity must be sufficient to reach fatigue thresholds encountered under sport conditions. Augustsson et al performed a study on functional hop testing in ACLR subjects and found that two thirds of subjects who had initially passed with greater than 90% limb symmetry index scores were unable to pass following a fatigue protocol for each lower extremity. Additionally, in this study lower extremity mechanics during testing were significantly negatively impacted by the fatigue protocol. This suggests that return to sport testing in a fatigued state may be beneficial to ensure that athletes are not cleared for return to play prematurely. The ability to maintain consistent movement quality and mechanics to avoid at-risk postures for ACL re-injury in the presence of fatigue is critical in rehabilitation planning and limiting injury risk in ACLR patients.

**PSYCHOLOGY AND INFLUENCE ON RETURN TO SPORT FOLLOWING ACLR**

Recent research has highlighted an enhanced understanding of psychological influence on the ability of ACLR patients to fully return to sport and restore performance to preinjury levels. Ardern et al showed that preoperative psychological responses were associated with likelihood of returning to preinjury levels 12 months after reconstruction. This may suggest that the role of psychology in the rehabilitation process has been underappreciated and further research may be warranted in this area. The most common reason cited in failure to return to sport is fear of reinjury. This fear of reinjury may manifest in the form of negative behaviors impacting sport performance including hesitation, giving less than maximal effort, and excessive protection of the affected body part during competition. Fear of reinjury or pain may also alter optimal motor function in the form of alterations in muscle tone, firing patterns, or sequential activation. There is evidence that motor control alterations in response to pain or musculoskeletal injury may persist despite the resolution of pain and symptoms. Acclimating the ACLR patient to the anticipated sport or recreational demands under controlled conditions may improve comfort level and confidence with these tasks in order to reduce or limit the negative impact of fear behaviors. Ardern et al reported that the prospective judgment ACLR patients made about their ability to return to sport included their own experience and attitudes as well as advice of health care professionals. This suggests the ability of rehabilitation providers to have a profound effect on the psychological attitudes of these patients through education, patient interactions, and customized neuromuscular training interventions that incorporate functional specificity during rehabilitation. Authors report significant efficacy and improvements in pain and fear of reinjury using education and in vivo exposure therapy for musculoskeletal conditions. While these studies are not specific to ACLR patients, they may be useful in developing rehabilitation strategies to address fear beliefs and kinesiophobia. Abbott et al also demonstrated superior effectiveness of post-operative rehabilitation incorporating psychomotor therapy consisting of cognition, behavior, and motor relearning versus exercise alone in patients recovering from lumbar fusion. De Jong et al hypothesized that graded in vivo exposure may also activate cortical networks and reconcile motor output and sensory feedback that may be altered due to pain and fear of reinjury in patients with Complex Regional Pain Syndrome (CRPS). Providers working with ACLR patients may provide exposure to a variety of advanced sport-specific movements during late stage rehabilitation to potentially improve psychological and neuromotor benefits. Early recognition of
ACLR patients demonstrating evidence of the psychological variables linked to less than optimal outcomes appears critical to improving overall rehabilitation success. Patients exhibiting these behaviors may benefit from consultation with a sports psychologist to remediate limiting factors and minimize re-injury risk. Many rehabilitation professionals lack the necessary training and psychology background to accurately identify patients demonstrating behaviors that are potentially detrimental to outcomes. Additionally, few peer-reviewed and researched post-operative ACLR protocols include screening tools to assist rehabilitation professionals in identifying these behaviors. Arder et al recently utilized the ACL-Return to Sport after Injury (ACL-RSI) as a screening tool to determine psychological readiness to return to sport and recreational activity. The authors correlated higher ACL-RSI scores with return to sports participation at pre-injury level. Chmielewski et al also demonstrated an association between scores on the Tampa Scale of Kinesiophobia (TSK) and function in the late stage rehabilitation period following ACLR from 6-12 months postoperatively. Higher TSK scores indicate greater pain-related fear of movement or reinjury. Pain-avoidance and fear-avoidance psychological factors have been demonstrated in an ACLR postoperative population as well. Lentz et al found that those who did not return to preinjury level of sports participation following ACLR because of fear of reinjury or lack of confidence demonstrated higher pain-related fear of movement. This supports the possibility that pain may alter neuromuscular function and pain avoidance behavior may have psychological implications that negatively impact rehabilitation. Rehabilitation professionals may find the above mentioned questionnaires or similar assessment tools useful to gauge psychological preparedness and aid in return to sport decision making, as well as to identify ACLR patients that may require additional interventions to enhance outcomes.

INTERVENTIONS
It has been well documented that deficits in range of motion and strength can negatively affect lower extremity performance and functional outcome following ACLR. For this reason, restoration of acceptable levels of ROM, strength, and biomechanics are essential components of a well designed rehabilitation program. Unfortunately, inclusion of these key components does not always correlate with successful return to previous level of activity. Traditional rehabilitation programs have produced variable results with respect to restoring symmetrical lower extremity muscle strength and activation, postural stability, and symmetrical movement mechanics. The traditional rehabilitation model has produced less than optimal success rates for return to athletic performance at preinjury levels. This suggests changes may be needed to the traditional ACLR rehabilitation paradigm to ensure improved patient outcomes. The resultant neuromotor effects of ACL injury and reconstruction are increasingly recognized but may not be properly resolved with traditional ACLR rehabilitation protocols, necessitating a change and willingness to adapt current rehabilitation practices. Emerging evidence-based rehabilitation strategies and concepts should be considered to remediate neuromotor changes.

Plyometric training is a mainstay in the mid and late rehabilitation phases of traditional ACLR rehabilitation protocols. Implementation of plyometrics is critical because early rehabilitation may not adequately simulate the forces required by full athletic participation and competition. ACLR patients who are not adequately prepared to accept and tolerate these forces and avoid at-risk postures and mechanics are more susceptible to re-injury. Plyometric training is often incorporated in conjunction with neuromuscular retraining with feedback to allow integration of improved lower extremity mechanics and simulate components of sports specific maneuvers. Plyometrics are an area where type of cuing and adequate supervision of movement mechanics may take on added importance due to the increased neuromuscular demand and higher loads and forces placed on the lower extremities.
influence motor control and neuromuscular re-education.\textsuperscript{115} The use of oral and video feedback has been shown to improve frontal plane lower extremity biomechanics during jumping tasks, improve strength, and decrease vertical ground reaction force.\textsuperscript{117} The use of combined verbal, visual, and tactile feedback has also allowed functional carryover of lower extremity biomechanics across multiple functional weight bearing tasks.\textsuperscript{114}

Recent research has focused on the effects of externally and internally directed cues and their respective impact on movement mechanics and motor learning. The type and method of cuing and feedback offered to ACLR subjects may have a significant effect on landing mechanics, lower extremity symmetry, and postural stability. Physical therapists provide feedback inducing internally directed focus up to 95\% of the time.\textsuperscript{116} Examples of internally directed cues may include instructing patients to land with flexed knees or to land with feet shoulder width apart.\textsuperscript{116} Recent evidence indicates that while use of internally directed cues may be more prevalent, it may actually limit potential for motor learning and full recovery following ACLR because it causes the patient to rely on more conscious versus automatic control at a central nervous system level.\textsuperscript{116} It has been suggested that cues involving externally directed focus may promote use of more unconscious or automatic mechanisms that may improve motor learning efficacy.\textsuperscript{116} Using external cues and targets such as cones, bars, or foot markers may allow patients to direct focus externally to improve quality of squatting, jumping, and sport-specific movements (Figures 1A and 1B).\textsuperscript{116} Feedback wording and supplied images with external cues describing technique such as land “light as a feather”, “like a spring” and “shock absorber” were also found to improve landing mechanics in both healthy and ACLR subjects.\textsuperscript{116} Improvements in jump distance and jump height during plyometric activities and training were observed using external attentional focus compared to internal attentional focus (Figures 2A and 2B).\textsuperscript{118-120} Multiple authors support improvements in force and athletic performance using externally directed attentional focus versus internally directed focus.\textsuperscript{119-121} Augmented verbal feedback coupled with plyometric training has also been demonstrated to increase power output in trained athletes during jumping tasks.\textsuperscript{118-120} Although it has not been studied specifically in an ACLR population, the enhanced benefits of external attentional focus during plyometric training may allow improved athletic performance and improved overall outcomes in ACLR subjects based on existing information from healthy subjects. Gokeler et al also found improvements in movement mechanics during single leg hopping in ACLR subjects using external attentional focus versus internal focus.\textsuperscript{121} Real time feedback is another means of incorporating external attentional focus. Real time visual feedback training utilizing mirrors and virtual reality images have recently been studied as a means of effectively altering neuromotor function and processing during both training and testing.\textsuperscript{117,122-124} Investigators used real time feedback training and found improvements in knee abduction load, knee flexion angle, and trunk postures found to correlate with ACL injury risk.\textsuperscript{117,121,122,124} However, a recent study comparing real time feedback training with traditional post-session visual or verbal feedback showed no added benefit to real time biofeed-

Figures 1A and 1B. Cones or similar objects may be utilized to facilitate improved lower extremity mechanics with jumping (Figure 1A) and landing/squatting (Figure 1B). Use of these external cues in conjunction with visual and verbal feedback will facilitate increased hip and knee flexion to encourage improved force absorption at the lower extremities and increased hamstring activation.
cortical pathways discussed previously, focused on internal cuing and more conscious nervous system regulation versus externally focused pathways that utilize more optimal autonomic regulation of neuromotor feedback and control. This is an interesting contrast to the theory employed during real-time feedback training, where visual input was used as a means to enhance neuromuscular function. Grooms et al. proposed that limiting visual input through the use of stroboscopic eyewear, computer or web-based applications to address visual processing, adding competing environmental stimuli (i.e., targets, reaction balls, etc.) (Figures 3A and 3B), or simply closing eyes during functional tasks and neuromuscular training in rehabilitation may help de-emphasize this over reliance on visual motor input. The authors of this approach emphasized that this is a hypothetical construct which currently lacks

back versus traditional means in improving sagittal or frontal plane kinematics. The lack of consensus on the effectiveness of real time feedback training coupled with the cost and limited availability of the equipment needed to implement it are areas of concern for practical use in the clinical setting.

One recently developed theoretical construct was proposed by Grooms et al. in order to incorporate specific visual motor rehabilitation approaches in conjunction with neuromuscular training to affect some of the documented neuromotor changes that occur following ACL injury and ACLR as discussed in this clinical commentary. This theoretical construct proposed that the detrimental neuromotor changes that occur following ACL injury and ACLR to efferent and afferent input, lead to a compensatory overreliance on the visual motor systems to provide adequate neuromuscular control and function at the involved knee. They proposed that this over reliance on visual motor input may actually lead to reinforcement of the detrimental top-down

Figures 2A and 2B. CImprovements in jump height and jump distance may be observed during plyometric training using external attentional focus on objects such as cones, targets, etc. placed at increased distance.

Figures 3A and 3B. The addition of competing environmental stimuli such as targets, balls, etc. during functional neuromuscular training may limit the overreliance on visual motor input for dynamic knee stability during sport-specific tasks.
substantial supporting evidence. However, there is some evidence to support this premise. Swanik et al found that athletes that suffered non-contact ACL injuries had slower visual processing scores on neurocognitive testing versus healthy controls.\textsuperscript{126}

**CONCLUSIONS**

Successful return to sport following ACLR is likely affected by multiple factors. The biomechanical risk factors for ACL injury have well been studied and documented.\textsuperscript{127} Strategies to avoid ACL injury\textsuperscript{128} and re-injury\textsuperscript{29} have been developed and examined. The disturbing rate of re-injury and unsatisfactory outcomes reported by a significant number of patients indicates that there may be barriers to optimal performance that need to be better recognized and addressed.

Research has shown that strength training in isolation does not guarantee improvements in hip and knee kinematics and that improved lower extremity strength does not guarantee improved landing technique.\textsuperscript{129} This suggests that while deficits in strength and activation ratios are serious factors that contribute to re-injury risk and sub-optimal performance, there are likely other contributing factors that may not be remedied with strength training alone. Additional neuromuscular retraining to simulate the specific movement patterns and environmental stimuli the athlete will encounter during sport may be required in conjunction with traditional strength training in order to achieve optimal movement quality and biomechanics. The evolution of targeted neuromuscular training programs to address biomechanical deficits in at risk athletes has been a significant development in functional rehabilitation over the last several years.\textsuperscript{28} In spite of this, the likelihood that up to one-third of athletes will re-tear the surgically reconstructed ACL or tear the ACL on the contralateral side implies that the improvements in biomechanics demonstrated in the rehabilitation setting do not reliably carry over to the playing field.\textsuperscript{9,14,15} For this reason, it is imperative that the rehabilitation professional continue to explore other factors that may negatively affect motor control and develop strategies to enhance outcomes.

Recent research examining the correlation between psychological preparedness and successful return to sport\textsuperscript{4,107-109} indicate that this is an area that may need to be addressed to improve outcomes. Based on the current evidence, it may be of significant benefit to the patient to utilize questionnaires or other measures to gauge psychological preparedness for discharge in the same manner that knee-specific patient reported outcome tools (like the International Knee Documentation Committee, Lysholm, Tegner, and Lower Extremity Functional Scale) are utilized to assess knee function and outcomes. Athletes who present with concerns in the psychological realm must be referred to a qualified provider to address these issues.

Testing to assess movement quality in both basic and sport specific patterns is an essential component of the return to sport decision making process. Assessment tools like the Functional Movement Screen\textsuperscript{TM} and Y Balance Test\textsuperscript{TM} have recently been validated in the literature as effective methods to assess injury risk.\textsuperscript{130-133} Metrics like these that assess competency in gross movement patterns may be valuable in determining readiness to return to the field. The FMS\textsuperscript{TM} and lower quarter version of the Y Balance Test\textsuperscript{TM} were recently studied in an adolescent population after an ACLR, and have been implemented to determine prospective injury risk and movement quality for safe return to sport.\textsuperscript{134} It is also essential that movement quality is assessed during dynamic activities that closely resemble sport requirement with regards to speed and force development. Significant work has been done to identify and target movement patterns and biomechanical flaws that increase injury risk during sport specific tasks like jumping, hopping, landing, and changing direction.\textsuperscript{128,135,136} Neuromuscular training philosophy has evolved and improved based on the work of these authors. These techniques will likely be further enhanced with greater understanding of optimal strategies to improve motor learning. This, coupled with a better understanding of the neuroplastic effect of ACL injury and the impact both the injury and subsequent surgery have on higher cortical areas will hopefully provide clinicians with valuable insight and more effective means to improve motor control and minimize injury risk. Finally, existing research regarding muscle activation and the effects of fatigue on function and performance suggest that it is essential that movement training and movement testing in a fatigued state be included in the rehabilitation pro-
It is important that the rehabilitation professional assess the athlete’s ability to perform in situations that most closely simulate the competition environment. This includes varying levels of stress, fatigue, and external stimuli. Rehabilitation programs have continuously improved over the past several years as evidence has emerged regarding biomechanical and neuromuscular risk factors for injury or reinjury. These programs will likely continue to evolve and become more efficient at minimizing injury risk as rehabilitation professionals continue to examine the intricate relationships between the various systems of the human body. Further research is necessary to optimally target deficits in neuromuscular control, neuromotor status, and psychological readiness to best prepare athletes for a return to the playing field following ACL injury.

REFERENCES


94. Webster KE, Santamaria LJ, McClelland JA, et al. Effect of fatigue on landing biomechanics after...


119. Porter JM, Anton PM, Wikoff NM et al. Instructing skilled athletes to focus their attention externally at...
greater distances enhances jumping performance.


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