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ABSTRACT

Background: Rotator cuff (RC) tendinopathy is a highly prevalent musculoskeletal disorder. Non-elastic taping (NET) and kinesiology taping (KT) are common interventions used by physiotherapists. However, evidence regarding their efficacy is inconclusive.

Objective: To examine the current evidence on the clinical efficacy of taping, either NET or KT, for the treatment of individuals with RC tendinopathy.

Study Design: Systematic review and meta-analysis

Methods: A literature search was conducted in four bibliographical databases to identify randomized controlled trials (RCT) that compared NET or KT to any other intervention or placebo for treatment of RC tendinopathy. Internal validity of RCTs was assessed with the Cochrane Risk of Bias tool. A qualitative or quantitative synthesis of evidence was performed.

Results: Ten trials were included in the present review on overall pain reduction or improvement in function. Most RCTs had a high risk of bias. There is inconclusive evidence for NET, either used alone or in conjunction with another intervention. Based on pooled results of two studies (n=72), KT used alone resulted in significant gain in pain free flexion (MD: 8.7° 95%CI 8.0° to 9.5°) and in pain free abduction (MD: 10.3° 95%CI 9.1° to 11.4°). Based on qualitative analyses, there is inconclusive evidence on the efficacy of KT when used alone or in conjunction with other interventions on overall pain reduction or improvement in function.

Conclusion: Although KT significantly improved pain free range of motion, there is insufficient evidence to formally conclude on the efficacy of KT or NET used alone or in conjunction with other interventions in patients with RC tendinopathy.

Level of Evidence: Therapy, level 1a

Keywords: Rotator cuff, taping, tendinopathy
INTRODUCTION
Shoulder pain affects a large portion of the population, with a reported lifetime prevalence ranging from 6.7 to 66.7%. While shoulder pain may result from various disorders, about two-thirds of cases are related to rotator cuff (RC) tendinopathy. RC tendinopathy is an umbrella term that encompasses several conditions such as shoulder impingement syndrome, RC tendinitis/tendinosis as well as subacromial bursitis.

The aetiology of RC tendinopathy is believed to be multifactorial and intrinsic as well as extrinsic factors are involved. Intrinsic factors relate to the degeneration of the RC tendons. Extrinsic factors contribute to the narrowing of the subacromial space, leading to impingement of the RC tendons. Extrinsic factors include: the presence of a type three acromion, biomechanical deficits such as altered humeral or scapular kinematics, changes in posture or inadequate muscle activation.

In rehabilitation, taping is a popular intervention for the treatment and prevention of many musculoskeletal disorders. For RC tendinopathies, when applied to the scapulothoracic and glenohumeral joints and their surrounding muscles, taping is believed to improve posture and shoulder kinematics as well as to decrease pain. There are two broad categories of taping: non-elastic taping (NET) and elastic kinesiology taping (KT). NET is characterized by a combination of minimal elasticity and high adhesive backing. The analgesic and the function-restoring effects of its application are believed to be related to its ability to change motor recruitment patterns as well as posture and to increase proprioception. NET has been utilized extensively for the rehabilitation of different upper and lower limb musculoskeletal (MSK) pathologies, such as patellofemoral syndrome, plantar fasciitis or lateral epicondylalgia and has been shown to reduce pain in the short term.

A single systematic review has focused on the effectiveness of tape application for upper-limb MSK pathologies but only included two trials targeting NET as a treatment of RC tendinopathy and no specific conclusions on the clinical efficacy of NET were offered. The use of KT has received widespread attention in recent years, especially among professional athletes. KT may be effective by decreasing pain via stimulation of peripheral modulation mechanisms, as postulated in the gate control theory of pain. It may also allow an increase in range of motion (ROM) by stimulating tissue blood flow. It is believed that gain in muscle strength is accomplished by exerting a concentric pull on the fascia and that improvement in proprioception is secondary to the stimulation of cutaneous mechanoreceptors. Finally, KT may lead to an increase or a decrease in muscle activation, depending on the tension applied on the tape during application. A recent systematic review that included solely quasi-experimental laboratory studies evaluating the possible physiological changes induced by the use of KT concluded that the evidence for its effects on pain, ROM, muscle strength and proprioception are limited. In terms of clinical efficacy, one recent systematic review assessing the impact of KT application on the management of different MSK pathologies, including RC tendinopathy, concluded that KT is not effective. The conclusions of that review were based on the inclusion of only two RCTs reporting results on individuals with RC tendinopathy.

Several new trials have been published since the publication of these reviews on the subject of the efficacy of NET and KT and some relevant trials were excluded from those reviews. Therefore, the objective of this systematic review was to examine the current evidence on the clinical efficacy of taping, either NET or KT, for the treatment of individuals with RC tendinopathy.

METHODS
Literature search and study identification
An electronic bibliographical search in MEDLINE, EMBASE, the Physiotherapy Evidence Database (PEDro) and the Cumulative Index to Nursing & Allied Health Literature (CINAHL) was conducted in order to identify citations indexed until October 2014. Tape, shoulder and RC tendinopathy-related terms were used as medical subject heading (MESH) terms and keywords (Figure 1). Manual search of reference lists of included studies and of previous reviews was also performed.

Study selection
Two evaluators independently reviewed the titles and abstracts of retrieved papers for inclusion in the pres-
ent review. In case of disagreement, a third reviewer was available in order to facilitate consensus. Inclusion criteria were: 1- participants were aged 18 years or older and presented a diagnosis of RC tendinopathy/tendinitis/tendinosis, partial RC tear, impingement syndrome or subacromial bursitis; 2- efficacy of a taping intervention (NET or KT) was compared to any other type of intervention or to a placebo; 3- study design was a randomized controlled trial (RCT); 4- article was written in English or French. Studies with participants that had either symptoms referred from the neck, full thickness or massive RC tear, or...
any postoperative conditions were excluded. No studies were excluded on the basis of the types of outcome measures used but the review focus on outcomes related to clinical efficacy such as pain and function.

Data extraction
Data and results of included studies were extracted with a standardized form that documented the number of participants and their characteristics, the type of intervention (including taping type and application parameters), the length of follow-up, the outcome measures (pain, function and impairments in ROM and strength) and results. When results were missing or incomplete, efforts were made to contact the contributing authors to retrieve missing data.

Risk of bias appraisal tool
As recommended by the Cochrane collaboration, the Cochrane Risk of Bias Tool was used to assess the internal validity of the included studies. Selection, performance, attrition, detection and reporting biases are appraised with this tool and are incorporated in eight domains (methodological items): sequence generation, allocation concealment, blinding of participants, blinding of personnel, blinding of outcome assessors, incomplete outcome data, selective reporting and other types of bias. Each domain was scored on a 3-point scale (0: high risk of bias, 1: unclear risk of bias, 2: low risk of bias) leading to a maximum of 16 points. The risk of bias was assessed by two independent reviewers and any differences were resolved by consensus. If consensus was not reached, a third reviewer was available.

Data analyses
Agreement between the total scores attributed to the methodological quality of the studies by the two reviewers was determined by calculating an intraclass correlation coefficient (ICC) using the Statistical Package for Social Sciences (IBM SPSS Statistics 21, Chicago, USA). The inter-rater agreement between the scores of each domain of the Cochrane Risk of Bias Tool was evaluated by means of the kappa (κ) statistic. Results from studies with similar comparators and outcome measures such as pain, function, ROM or strength were considered for pooling into separate meta-analyses. Only meta-analyses without a significant degree of heterogeneity (χ² p > .10 and I² < 60%) were kept and reported. Mean differences (MD) with 95% confidence intervals (CI) were calculated using Review Manager (RevMan 5.2, The Cochrane Collaboration, Copenhagen, Denmark). Alpha level was set at 0.05. Funnel plots were not generated if the number of trials included in the meta-analysis was small. When quantitative pooling was not performed, results were qualitatively synthesized.

RESULTS

Description and findings of included studies
Figure 1 shows the flow chart of study selection. Ten RCTs were included in the present review. Results of one study were presented in two separate articles, which were therefore analysed together. Included trials evaluated the efficacy of taping alone, in conjunction with mobilizations with movement, (MWM) with exercises, or with manual therapy and exercises. Four trials evaluated NET while the other trials evaluated KT. Appendix 1 presents the details of these studies. Pain was assessed with a VAS (Visual Analogue Scale) in four trials, and in five trials a validated functional outcome measure was used.

Overall efficacy of taping (NET or KT)
Because of significant heterogeneity (χ² p < .10 and I² > 60%), pooling of results (any outcomes) was not possible to evaluate overall efficacy of NET or KT.

Efficacy of Non elastic taping
Because of significant heterogeneity (χ² p < .10 and I² > 60%), pooling of results was not possible for any studies evaluating the efficacy of NET; a qualitative synthesis was therefore performed.

Efficacy of NET compared to placebo taping
One placebo-controlled cross-over trial by Lewis et al evaluated the immediate effects of NET compared to placebo taping. The experimental taping consisted of four bands: two from the 7th (T7) to the 12th (T12) thoracic vertebrae and two from the center of the scapula to T12 in order to decrease thoracic kyphosis. Placebo taping consisted in the application of a five centimeter-wide piece of Fixomull (Hamburg, Germany) tape over the same location as the NET and active postural changes were not encouraged in the
placebo setting. Pain at the end of the ROM in either flexion or elevation in the scapular plane was not significantly decreased with the NET (10 cm VAS mean difference [MD] in flexion: -0.4; 99% CI: -1.1 to 0.3 and in scaption: -0.4; 99% CI: -1.0 to 0.2). However, the pain free ROM was increased (MD in flexion: 16.2°; 99% CI: 7.9° to 24.4° and in scaption: 14.7°; 99% CI: 5.7° to 23.6°) compared to placebo taping. Moreover, significant postural changes manifested by reduced forward head posture, scapular protraction and thoracic kyphosis were observed using a 3D motion capture system, in favour of the experimental taping condition (p<0.01).

**Efficacy of NET in conjunction with other interventions**

Three RCTs contrasted the efficacy of a multimodal intervention to an additional combination with NET. Kumar et al evaluated the effects of adding NET (as described by Lewis et al) to a multimodal rehabilitation program (education, ice, soft tissue mobilizations, stretching and strengthening exercises). At six weeks, significant differences in function measured with the Shoulder Pain and Disability Index (SPADI) (MD: 6.3% ± 2.6; p=0.024) and in muscle strength (flexion, abduction, internal and external rotation assessed with isometric dynamometry; p<0.05) were reported in favour of the group with NET. In the study by Miller and Osmotherly, the experimental group received NET (two bands to correct internal rotation and anterior tilt of the scapula) for the two first weeks of a six-week rehabilitation program consisting of soft tissue and joint mobilizations, stretching and strengthening exercises. Pain during movement and function (measured with the SPADI) were assessed and the magnitude of the estimates of change was above the minimal clinically important difference (MCID) in favour of the taping group however, results did not reach statistically significant differences (p≥0.05). Active ROM in flexion and abduction were also assessed and no differences between groups were observed at two or six weeks after treatment (p≥0.05). Teys et al evaluated the added benefits of NET intervention (anterior deltoid to T7 spinous process) to MWM. Current pain, pain free scapular plane elevation and pressure pain threshold were assessed immediately, 30 minutes, 24 hours, and 7 days following tape application. The group receiving MWM with NET showed greater gains in pain free scapular plane elevation immediately after the initial application (MD: 7.5° 99% CI: 1.2° to 13.8°) and at 7 days (MD: 15.9° 99% CI: 7.4° to 24.4°), but no significant differences were found between groups (p≥0.05) at any of the other time points or in any outcome measures.

**Efficacy of Kinesiology taping**

**Efficacy of KT compared to a placebo**

Three RCTs evaluated the efficacy of KT compared to a sham taping intervention. Pooling of results was only possible for two of these RCTs (n=72) regarding pain free ROM outcome after one week. Pooled data showed a significant difference between groups in favour of the KT intervention for pain free flexion (MD: 8.7° 95%CI 8.0° to 9.5°), abduction (MD: 10.3° 95%CI 9.1° to 11.5°) and elevation in the scapular plane (MD: 7.6° 95%CI 6.3° to 8.9°). (Figures 2-4) Thelen et al compared KT (Kinesio Tex, Albuquerque, USA) application (first band with a 10% stretch over the deltoid and supraspinatus muscles, second band with 50% to 75% stretch from the coracoid process around to the posterior deltoid) to sham taping (two bands applied without tension from anterior to posterior across the acromio-clavicular joint and the distal deltoid). Pain free ROM was recorded immediately, three and six days fol-

---

**Figure 2. Kinesiology Taping Versus Placebo: Pain Free Flexion.** Forest plot of pooled studies comparing KT alone to placebo for change in pain free flexion. The squares are mean differences and the diamond is the pooled mean difference with 95% confidence interval.
applied in the same manner but without any tension (sham application). Marginal statistically significant differences in isometric strength were observed in favour of the experimental group (MD: 2.7 lbs ± 3.9; p = 0.05).

Efficacy of KT in conjunction to a multimodal intervention compared to another intervention

Simsek et al.28 compared the addition of KT (Kinesio Tex, Alburquerque, USA) to an exercise program. Both groups received an exercise program consisting of strengthening of the RC muscles. The experimental group received KT and the control group sham taping as described by Thelen et al.24 There were no changes in the pain level at rest, but significant differences between groups were observed for the pain level during activity (10 cm VAS score: MD at 5 days: 1.0 ± 0.85 p = 0.01 and at 12 days: 1.1 ± 0.94 p = 0.009). Functional differences between groups were also measured at five and 12 days with the DASH and the Constant Murley Score (CMS). Authors reported differences in favour of the experimental group on the DASH (MD at five days: 11.4% ± 8.3 p = 0.004; at 12 days: 15.4% ± 8.2 p = 0.001) but not on the CMS (MD at five days: 10.0% ± 6.3 p = 0.339; at 12 days: 12.1% ± 6.3 p = 0.146). Pain free ROM, active and passive ROM and isometric muscle

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<th>Study or Subgroup</th>
<th>Experimental Mean SD Total</th>
<th>Control Mean SD Total</th>
<th>Mean Difference IV, Fixed, 95% CI Year</th>
<th>Mean Difference IV, Fixed, 95% CI</th>
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<tr>
<td>Thelen 2008</td>
<td>36.3 33.9 21 25.7 23.1 21 0.5% 10.30 [-7.25, 27.85] 2008</td>
<td>Total (95% CI) 36 100.0% 10.26 [9.07, 11.45]</td>
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<td>Test for overall effect: Z = 16.86 (p &lt; 0.00001)</td>
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Favours placebo Favours KT

Figure 3. Kinesiology Taping Versus Placebo: Pain Free Abduction. Forest plot of pooled studies comparing KT alone to placebo for change in pain free abduction. The squares are mean differences and the diamond is the pooled mean difference with 95% confidence interval.

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<th>Study or Subgroup</th>
<th>Experimental Mean SD Total</th>
<th>Control Mean SD Total</th>
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<tr>
<td>Thelen 2008</td>
<td>25.9 28.1 21 20.4 21.9 21 0.7% 5.50 [-9.74, 20.74] 2008</td>
<td>Total (95% CI) 36 100.0% 7.59 [6.33, 8.84]</td>
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<tr>
<td>Shakeri 2013</td>
<td>15.67 1.55 15 8.07 1.94 15 99.3% 7.60 [6.34, 8.86] 2013</td>
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Favours placebo Favours KT

Figure 4. Kinesiology Taping Versus Placebo: Pain Free Elevation in the Scapular Plane. Forest plot of pooled studies comparing KT alone to placebo for change in pain free elevation in the scapular plane. The squares are mean differences and the diamond is the pooled mean difference with 95% confidence interval.

Thelen et al.24 also recorded the degree of pain during movement and the level of function, as measured with the SPADI. No significant differences between groups were observed in either outcome (p ≥ 0.05). Shakeri et al.29 observed a significant difference in terms of pain at the end of ROM immediately after treatment (10 cm VAS score MD: 1.7. p = 0.009, SD not reported) but not at three and seven days (p ≥ 0.05). Increased function, measured with the Disability of Arm, Shoulder and Hand (DASH) questionnaire, at seven days was also observed (MD: 13.4% ± 7.0 p = 0.01).29 Hsu et al.21 compared the immediate differences in isometric strength in scapular plane elevation between KT (Kinesio Tex, Tokyo, Japan) applied with minimal tension over the lower trapezius and a 3M Micropore tape (3M, St. Paul, USA) applied in the same manner but without any tension (sham application). Marginal statistically significant differences in isometric strength were observed in favour of the experimental group (MD: 2.7 lbs ± 3.9; p = 0.05).
strength were also assessed. Significant differences were only observed for pain free ROM in abduction at 12 days, strength in flexion at five and 12 days and strength in external rotation at 12 days in favour of the treatment group (p < 0.05). Significant differences were also noted for active flexion at five and 12 days as well as for passive flexion at five days (p < 0.05); in this case, the differences were observed in favour of the control group.

The trial by Djordjevic et al. compared KT (Kinesio Tex, Alburquerque, USA) using three bands over the supraspinatus and deltoid as well as over the glenohumeral joint with a 20-25% stretch, combined with MWM to supervised exercises (active pain free ROM and isometric muscle strengthening). At ten days, the authors reported significant differences in pain free flexion (MD: 94.0° ± 12.3 p = 0.000) and in pain free abduction (MD: 102.5° ± 11.0 p = 0.000) in favour of the combined intervention. No other outcome was measured in this study.

The trial by Kaya et al. compared KT (Kinesio Tex, Alburquerque, USA) using four bands (deltoid, supraspinatus and mechanical correction of glenohumeral as well as the acromio-clavicular joints) and exercises (active ROM exercises, stretching, strengthening of the shoulder girdle) to a manual therapy intervention (mobilization of shoulder girdle, neck and cervical spine, soft tissue massage, deep friction massage) with exercise. At six weeks the authors reported no significant difference between groups for pain during activity or function as measured by the DASH (p > 0.05) but observed a significant pain reduction at night for the KT and exercises group (10 cm VAS score: MD: .96 ± 0.22 p = 0.01).

Risk of bias results

The mean score across all studies as measured by the Cochrane Risk of Bias Tool was 54.4% ± 10.6 and scores ranged from 6/16 (37.5%) to 11/16 (68.8%). In terms of reviewers’ agreement for the risk of bias tool, the ICC for the overall score was high: 0.82 (95% CI: 0.38 to 0.95) and the inter-reviewer agreement on individual items of the tool ranged from moderate (incomplete data: $\kappa$ = 0.51) to perfect (selective reporting $\kappa$ = 1.00).

None of the studies had a low risk of bias for each of the eight items. Blinding of providers was impossible due to the nature of the intervention. Allocation concealment was only adequately reported in one trial. In one third of the RCTs, blinding of participants or assessors was not carried out. Eight RCTs did not provide a protocol or trial registration number, therefore reporting bias was potentially present in most RCTs (Figures 5 and 6).

DISCUSSION

The goal of this systematic review was to assess the clinical efficacy of taping for patients with RC tendinopathy. Ten RCTs were included and the studies’ risk of bias was moderate to high. Overall, there is insufficient evidence regarding the efficacy of taping, either NET or KT, in order to elaborate clear recommendations. However some of the included studies appear to show some clinical efficacy and

![Figure 5. Risk-of-bias graph: review authors’ judgments about each risk-of-bias item, presented as percentages across all included studies.](image-url)
Three trials investigated the effects of adding NET to either a comprehensive physiotherapy program or to MWM. Again, there is inconclusive evidence that the addition of NET to another intervention may be beneficial in terms of pain, function or reduction of impairments in domains such as ROM and shoulder muscle strength. Two of these trials with a moderate to high risk of bias found a significant difference in terms of pain at rest, function and muscle strength but those changes were not clinically important; pain free ROM improvements were however found to be statistically significant and clinically important in only one of the trials. Finally, in the trial by Miller and Osmotherly, a study considered at high risk of bias, the authors observed a non-significant difference between the two groups in terms of pain and function but the magnitude of the estimates of change was above the minimal clinically important difference (MCID) in favour of the taping group; because of its small sample size (n=22) and the high variability of the dependent variable, it is likely that the study was statistically underpowered.

Regarding the efficacy of KT, when compared to placebo, pooled results of two RCTs demonstrating moderate risk of bias showed a significant improvement in pain free ROM and this may be clinically important as the effect size was greater than 0.9. However, in relation to other outcomes, these two RCTs did not observe any effect on overall pain and the results are contradictory concerning function. Marginally significant gains in shoulder muscle strength were observed in another trial (p=0.05). The difference reported by the author was 2.7 ± 3.9 lbs and again this gain could be clinically important (effect size = 0.75).

There is also a lack of evidence on the efficacy of KT used with other interventions such as exercises or MWM. Two RCTs with moderate to high risk of bias did not provide clear conclusions about any potential efficacy. The RCT by Simsek et al reported results for active ROM, muscle strength, pain at rest and during activity but no clinically important differences were observed. Even though no impairment-based outcomes (pain at rest and during activities, pain free ROM, active and passive ROM, muscle strength) were clinically improved, functional improvements were reported: the difference in DASH score was

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**Specific findings**

Results from one RCT presenting a high risk of bias showed that when compared to a placebo, NET alone may immediately increase pain free ROM and lead to changes in posture but did not decrease pain levels during movement. Although these results somewhat support the intended therapeutic effect of taping, it remains unclear whether these results may translate into clinically important differences in pain reduction and improvement in function in the medium or long term.

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**Table 6. Detailed methodological assessment of included studies using the Cochrane risk-of-bias tool.** Green, low risk of bias; red, high risk of bias; yellow, unclear or unknown risk of bias.
higher than the MCID of 10.2 and gains in CMS were substantial and may be considered clinically important.\textsuperscript{30} In the RCT by Djordjevic et al,\textsuperscript{40} statistically significant and clinically important changes in pain free ROM were observed in the KT and MWM group when compared to the exercises and MWM group. In the other RCT by Kaya et al,\textsuperscript{19} no significant differences were reported for pain reduction or function improvement when KT and exercises were compared to manual therapy and exercises.

Variations in treatment efficacy observed in the different studies may be explained by several factors such as heterogeneity in length of follow-up and participant characteristics; however, the taping application protocols appear similar across studies. Indeed, multiple trials used a similar protocol for taping techniques and placement. However, even though the protocols were comparable, disparities may still exist in the application between studies or within studies when multiples treatment providers were used. In trials with longer follow-ups, the same taping was kept on the skin for two to three days, and then renewed.\textsuperscript{16-18,23,24,28} A sustained therapeutic effect may be questionable in the case of maintaining the placement of the tape for such long periods of time. Indeed, evidence from other types of NET at the ankle joint, suggests a clinical efficacy of 45 minutes or less in terms of restriction of movement.\textsuperscript{32} This factor may therefore also account for differences observed in the present studies.

Another important factor to be considered is the fact that taping only addresses some of the possible aetiologies of RC tendinopathy, namely inadequate shoulder girdle kinematics caused by muscle imbalance or poor posture. For a subgroup of patients, tendinopathy may be present because the subacromial space is narrowed by excessive thoracic kyphosis and inferior rotation or anterior tilting of the scapula.\textsuperscript{33,34} In this subgroup, NET aimed at correcting posture would logically be more appropriate. On the other hand, KT might benefit subgroups of patients but the physiological effects of KT are still unclear and this subgroup is yet to be identified.\textsuperscript{14} Theses hypotheses are interesting avenues of research as they represent current clinical concepts and clinical decision making regarding treatment interventions but, they need to be formally evaluated in future trials. Also, it seems reasonable to posit that taping is more efficacious when combined with another intervention such as exercise, as it would decrease pain and could improve exercise execution. However, results from the current systematic review are unclear on that matter.\textsuperscript{35-37} In order to be able to make formal recommendations about the efficacy of taping (NET or KT) alone or combined with another modality, methodologically sound RCTs with larger sample sizes using validated outcome measures with blind assessors and longer follow-up periods are clearly needed.

Similar to the two most recent systematic reviews on KT for other MSK disorders, the authors’ conclude that there is no clear evidence that allows the presentation of any clinical recommendation on the uses of KT for RC tendinopathy. Even though the current review included nine new studies the results remain in line with those of Williams et al\textsuperscript{14} and Mostafavifar et al\textsuperscript{38} who focused on KT for different upper and lower limb MSK pathologies. Recently, another review that included the latest evidence concluded that KT is ineffective for the treatment of various MSK pathologies.\textsuperscript{15} To the author’s knowledge, the current review is the first systematic review to attempt to draw specific conclusions about the efficacy of NET for RC tendinopathy.

**STRENGTHS AND LIMITATIONS OF THE REVIEW**

Strengths of this review are the detailed literature search conducted in four important databases and the use of the validated Cochrane Risk of Bias tool to evaluate the methodological quality of included studies. Despite the relatively homogenous taping interventions (two out of four RCT used the same non-elastic taping and three out five RCTs used the same KT), pooling of data was limited because of significant heterogeneity.

**CONCLUSION**

Some studies seem to demonstrate a treatment effect, although the clinical importance of this effect is unclear. Because of the high risk of bias and the heterogeneity of results of the included studies, the authors cannot, at this time, formally recommend taping for treatment of RC tendinopathy. There is insufficient evidence to formally conclude on the efficacy of NET used alone or in conjunction with
other interventions to treat RC tendinopathy. For KT, evidence exists that it might improve pain free ROM but those improvements do not translate into pain reduction and increased function. Regarding the efficacy of KT in conjunction with another intervention, there is insufficient evidence to recommend this approach. More methodologically sound studies on the efficacy of taping for RC tendinopathy are therefore needed.

REFERENCES


## APPENDIX 1. Characteristics of the included studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Groups</th>
<th>Interventions</th>
<th>Follow-up period</th>
<th>Outcome measures</th>
<th>Main results</th>
<th>Risk of bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>Djordjević et al 2012</td>
<td>Gender: Male 7, Female 13</td>
<td>Group 1: KT and MWM</td>
<td>3 bands: supraspinatus, deltoid and glenohumeral joint, 20-25% stretch taping renewed at 5 days (Kinesio Tex, Albuquerque, USA)</td>
<td>10 days</td>
<td>Pain free flexion (*)</td>
<td>Pre-post differences within groups: 1:11.0 ± 3.51; 1117 ± 27.5</td>
<td>11/16</td>
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<tr>
<td></td>
<td>Mean age: 55.0 ± 8.6</td>
<td>Group 2: Supervised exercises</td>
<td>Pain free abduction (*)</td>
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<td></td>
<td>Diagnosis: combination of positive tests (Neer impingement sign, Hawkins-Kennedy test, empty can test), active and passive ROM, ultrasound and radiographic imaging</td>
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<tr>
<td>Hoa et al 2009</td>
<td>Gender: proportion not mentioned</td>
<td>Group 1: KT</td>
<td>1 band: lower trapezius, minimal tension (Kinesio Tex, Tokyo, Japan)</td>
<td>Immediately after tape application</td>
<td>Isometric strength in scapulation (lbs)</td>
<td>Pre-post differences within groups: 1: 2.9 ± 3.9; 2: -0.7 ± 0.3</td>
<td>10/16</td>
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<td></td>
<td>Mean age: 23.0 ± 2.8</td>
<td>Group 2: Placebo</td>
<td>Sham taping</td>
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<td></td>
<td>Diagnosis: 1) positive Neer impingement sign or Hawkins-Kennedy test and 2) at least 2 of the following: relevant history, painful arc in scapulation, pain with greater tuberculosis palpation, pain with resisted abduction</td>
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<tr>
<td>Kaya et al 2014</td>
<td>Gender: Male 21, Female 33</td>
<td>Group 1: KT and exercises</td>
<td>4 bands: deltoid, supraspinatus, glenohumeral and acromio-clavicular joint, taping applied once a week and kept 4-5 days (Kinesio Tex, Albuquerque, USA); active ROM exercises, stretching, strengthening of the shoulder girdle</td>
<td>6 weeks</td>
<td>Pain during activity and at night (VAS)</td>
<td>Pre-post difference within groups: 1: 3.3 ± 0.65 p&lt;0.001; 2: 2.7 ± 0.45 p&lt;0.01</td>
<td>9/16</td>
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<tr>
<td></td>
<td>Mean age: 49.0 ± 2.16</td>
<td>Group 2: Manual therapy and exercises</td>
<td>Mobilization of shoulder girdle, neck and cervical spine, soft tissue massage, deep friction massage</td>
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<tr>
<td></td>
<td>Diagnosis: positive Hawkins-Kennedy test, painful arc sign, and infraspinatus muscle test</td>
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<tr>
<td>Kumar et al 2012</td>
<td>Gender: Male 36, Female 16</td>
<td>Group 1: NET and home exercises program</td>
<td>2 bands: T1 to T12 and center of scapula to T12 taping renewed 3 times a week</td>
<td>6 weeks</td>
<td>SPADI (%)</td>
<td>Pre-post difference within groups: 1: 52.2 ± 9.8; 2: 45.9 ± 9.5</td>
<td>9/16</td>
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<td></td>
<td>Mean age: 36.2</td>
<td>Group 2: Standard care and exercises</td>
<td>Ice, soft tissue mobilization, education, active ROM, stretching, strengthening</td>
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<td>Diagnosis: At least 4 of the following positive tests: Neer impingement sign, Hawkins-Kennedy test, empty can test, painful arc, pain with greater tuberculosis palpation</td>
<td>Total cohort n=52</td>
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<tr>
<td>Lewis et al 2005</td>
<td>Gender: Male 35, Female 25</td>
<td>Group 1: NET</td>
<td>2 bands: T1 to T12 and center of scapula to T12 taping</td>
<td>Immediately after tape application</td>
<td>Pain on movement (10 cm VAS)</td>
<td>Differences between groups: flexion: -0.4999/C1 -1.1 to 0.3 abduction: -6.4999/C1 -1.0 to 0.2</td>
<td>6/16</td>
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<td></td>
<td>Mean age: 48.9 ± 15.2</td>
<td>Group 2: Placebo</td>
<td>Sham taping</td>
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<td>Diagnosis: At least 4 of the following positive tests: Neer impingement sign, Hawkins-Kennedy test, empty can test, painful arc, pain with greater tuberculosis palpation</td>
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<tr>
<td>Miller and Oromelyther 2009</td>
<td>Gender: Male 10, Female 12</td>
<td>Group 1: NET for 2 first weeks and classic physiotherapy for 6 weeks</td>
<td>2 bands: anterior deltoid to medial end of the scapula spine; coracoid process to the middle of the scapula medial border, taping renewed 3 times a week</td>
<td>2 weeks (directly after the end of the tape application for group 1) and 6 weeks (from week 2 to 6 no tape application)</td>
<td>Pain on movement (10 cm VAS)</td>
<td>Median score (interquartile range) at 2 weeks</td>
<td>8/16</td>
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<tr>
<td></td>
<td>Mean age: 58.3</td>
<td>Group 2: Classic physiotherapy for 6 weeks</td>
<td>Soft tissue massage and joint mobilization techniques, scapula and rotator cuff stabilization exercises, stretches and general strengthening of the shoulder</td>
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<tr>
<td></td>
<td>Diagnosis: positive Hawkins-Kennedy test</td>
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### APPENDIX 1. (Continued)

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<tr>
<th>Study</th>
<th>Participants</th>
<th>Groups</th>
<th>Interventions</th>
<th>Follow-up period</th>
<th>Outcome measures</th>
<th>Main results</th>
<th>Risk of bias</th>
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<tr>
<td></td>
<td></td>
<td>Group 1: KT</td>
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<td></td>
<td>Mean score (interquartile range) at 2 weeks</td>
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<tr>
<td></td>
<td></td>
<td>n= 15</td>
<td>3 bands: deltoid and supraspinatus muscle (10% stretch); coracoacromial process around to the posterior deltoid (50% to 75% stretch); strengthening of the RC</td>
<td>Immediately, 3 days, 7 days</td>
<td>Pain at end range</td>
<td>Prepost difference within groups immediately</td>
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<td></td>
<td></td>
<td>Group 2: Placebo</td>
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<td>1: 2.1 ± 0.7 2: 6.4 ± 0.7</td>
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<td></td>
<td></td>
<td>n= 15</td>
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<td></td>
<td>Difference between groups 1.7 p=0.009</td>
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<tr>
<td>Shakeri et al 2013</td>
<td>Gender:</td>
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<td>No statistically significant difference between groups at 3 and 7 days p=0.05</td>
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<td>proportion not reported</td>
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<td>Prepost differences within groups at 7 days</td>
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<td></td>
<td>Mean age: 46.6 ± 13.8</td>
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<td>1: 16.1 ± 6.9 p=0.001 2: 4.7 ± 0.8 p=0.02</td>
<td>10/16</td>
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<td>Diagnosis: 1) positive Neer impingement sign or Hawkins-Kennedy test or Yocum test and 2) at least 2 of the following: relevant history, painful arc in scapular pain with greater tuberosity palpation, pain with resisted abduction</td>
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<td>Difference between groups: 13.4 ± 7.0 p&lt;0.05</td>
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<td></td>
<td>Group 2: Placebo</td>
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<td>Pain free ROM (Flexion, Abduction, Scapular Elevation)</td>
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<td></td>
<td>n= 15</td>
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<td>No statistically significant difference between groups immediately, at 5 and 12 days for all movements p&lt;0.05</td>
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<tr>
<td>Simsek et al 2013</td>
<td>Gender:</td>
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<td></td>
<td>Mean score (interquartile range) at 2 weeks</td>
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<td></td>
<td>Male: 19</td>
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<td>1: 21.4 ± 16.0 p&lt;0.001 2: 5.5 ± 18.5 p&lt;0.001</td>
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<td></td>
<td>Female: 19</td>
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<td></td>
<td>Difference between groups at 5 days 10.9 ± 6.3 p=0.339</td>
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<td>Mean age: 51.0</td>
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<td>Difference between groups at 12 days 12.3 ± 6.3 p=0.146</td>
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<td>Diagnosis: positive Neer impingement sign and Hawkins-Kennedy test</td>
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<td>Difference between groups at 12 days 11.4 ± 8.3 p&lt;0.004</td>
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<td></td>
<td>Group 1: KT taping and exercises</td>
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<td>5 and 12 days</td>
<td>Pain at rest (10 cm VAS)</td>
<td>Prepost difference within groups at 5 days</td>
<td>1: 10 ± 4.3 p&lt;0.001 2: 6.6 ± 4.3 p&lt;0.001</td>
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<td>n= 19</td>
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<td>Difference between groups at 5 days 4.3 ± 1.2 p=0.003</td>
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<td>Group 2: Placebo and exercises</td>
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<td>Pain during activity (10 cm VAS)</td>
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<td>n= 19</td>
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<td>Prepost difference within groups at 5 days</td>
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<td>1: 2.3 ± 3.1 p&lt;0.001 2: 1.3 ± 2.1 p&lt;0.001</td>
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<td>Difference between groups at 5 days 1.0 ± 0.85 p&lt;0.010</td>
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<td>Difference between groups at 12 days 1.8 ± 0.59 p&lt;0.001</td>
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<td>Prepost difference within groups at 5 days</td>
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<td>1: 16.0 ± 26.6 p&lt;0.001 2: 4.6 ± 24.8 p&lt;0.01</td>
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<td>Difference between groups at 5 days 11.4 ± 8.3 p&lt;0.004</td>
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<td>Difference between groups at 12 days 15.4 ± 8.2 p&lt;0.001</td>
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<td>1: 15.5 ± 26.4 p&lt;0.001 2: 5.5 ± 18.5 p&lt;0.001</td>
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<td>Difference between groups at 5 days 10.9 ± 6.3 p=0.339</td>
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<td>Difference between groups at 12 days 12.3 ± 6.3 p=0.146</td>
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## APPENDIX 1. (Continued)

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<tr>
<th>Study</th>
<th>Participants</th>
<th>Groups</th>
<th>Interventions</th>
<th>Follow-up period</th>
<th>Outcome measures</th>
<th>Main results</th>
<th>Risk of bias</th>
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<tbody>
<tr>
<td>Teys 2013</td>
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<tr>
<td>Gender</td>
<td></td>
<td>Cross-over trial n=25</td>
<td></td>
<td></td>
<td>Pain free active ROM in flexion, abduction, internal and external rotation (°)</td>
<td>Difference between groups favoring group 1 for abduction at 12 days 25.1 ± 8.7; p=0.004</td>
<td>7/16</td>
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<tr>
<td>Male: 15</td>
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<td></td>
<td>No statistically significant difference between groups at 5 and 12 days for all other movements p&gt;0.05</td>
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<tr>
<td>Female: 10</td>
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<td>Mean age: 45.4± 14.8</td>
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<td>Active and passive ROM in flexion, extension, abduction, external, and internal rotation (°)</td>
<td>Difference between groups favoring group 2 for active flexion at 5 days 14.0 ± 6.2 p=0.002; 12 days 7.2 ± 5.3 p=0.04 for passive flexion at 5 days ± 2.84 p=0.03</td>
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<tr>
<td>Diagnosis: reduced shoulder elevation and limited painful abduction</td>
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<td>Group 1: NFT and MWM</td>
<td>1 band: anterior deltoit to T7 tape was removed after 48h</td>
<td>Immediately, 30 min, 24h, 7 days</td>
<td>Pain free scapulation (°)</td>
<td>No statistically significant difference between groups at 5 and 12 days for all other movements p&gt;0.05</td>
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<td>Inclusion criteria: must respond to MWM (10 degree improvement)</td>
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<td>Group 2: MWM</td>
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<td>Theilen et al 2008</td>
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<td>Isometric muscle strength (kg-force)</td>
<td>Difference between groups favoring group 1 for strength in flexion at 5 days 1.8 ± 1.0; p=0.05 at 12 days 2.8 ± 0.0; p=0.005 external rotation at 12 days 2.2 ± 0.9 p=0.03</td>
<td>10/16</td>
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<tr>
<td>Gender</td>
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<td>Cross-over trial n=21</td>
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<td>No difference between groups for all other movement and time points p&gt;0.05</td>
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<td>Male: 36</td>
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<td>Female: 6</td>
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<td>Mean age: 20.5</td>
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<tr>
<td>Diagnosis: shoulder pain onset prior to 150° in any plane, positive Hawkins-Kennedy test and empty can test</td>
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<td>Group 1: KKT n=21</td>
<td>3 bands: deltoit and supraspinatus (10% stretch), conoid process around the posterior deltoit (50% to 75% stretch) taping renewed at day 3 (Kinesio Tex, Albuquerque, USA)</td>
<td>Immediately after treatment, 3 and 6 days</td>
<td>Pain at the end of range of active ROM (abduction, flexion and scapulation) (100 mm VAS)</td>
<td>Difference between groups favoring group 1 post intervention: 4.7 99%CI [-4.7 to 14.7] at 3 days: 3.8 99%CI [-11.6 to 19.2] at 6 days: 3.3 99%CI [-13.8 to 20.5]</td>
<td></td>
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<tr>
<td>Group 2: Plaque n=21</td>
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<tr>
<td>Pain free active ROM in abduction, flexion and scapulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SPADI (%)</td>
<td>Difference between groups favoring group 1 at 3 days: -0.9 99%CI [-9.9 to 8.1] at 6 days: -2.2 99%CI [-14.7 to 10.4]</td>
<td></td>
</tr>
<tr>
<td>KT: Kinesiology tape</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pain free active ROM in abduction, flexion and scapulation</td>
<td>Differences between groups for abduction post intervention: 19.1 99%CI [1.7 to 36.5]</td>
<td></td>
</tr>
<tr>
<td>NET: Non-elastic taping</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No statistically significant differences between groups at other time points for all other movements (p&gt;0.05)</td>
<td></td>
<td></td>
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<tr>
<td>RC: rotator cuff</td>
<td></td>
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<tr>
<td>T7 and T12: 7th and 12th thoracic vertebrae</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>ROM: range of motion</td>
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<td></td>
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</tr>
<tr>
<td>VAS: visual analog scale</td>
<td></td>
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<tr>
<td>DASH: Disability of the arm shoulder and hand: self-reported disability questionnaire, higher scores indicate a greater level of disability</td>
<td></td>
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<tr>
<td>CMS: Constant-Murley score: pain and function questionnaire, isometric abduction strength, active ROM in flexion, abduction, internal and external rotation, higher scores indicate a greater level of function</td>
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<tr>
<td>SPADI: Shoulder Pain and Disability Index: Self-assessment of symptoms and function of the shoulder, higher scores indicate a greater level of disability</td>
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<tr>
<td>CI: confidence interval</td>
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</table>
ABSTRACT

Background: There is little research on how the amount of shoulder joint range of motion, specifically glenohumeral rotation, may be related to the muscle strength of the rotator cuff muscles. A long held belief is that a joint with excessive range of motion needs sufficient muscular strength for stability. However, no studies have examined this concept.

Purpose: The purpose of this study was to see if total arc of glenohumeral joint rotation (External rotation [ER]+Internal rotation [IR]) could predict peak isometric muscle strength of the IR or ER muscles of the shoulder.

Study Design: Cross-sectional study design

Methods: Fifty-three participants (41 females, 12 males) participated in the study. Passive glenohumeral joint internal rotation and external rotation motion was measured for each participant with a standard goniometer. Isometric muscle force of the ER and IR muscles were tested using a handheld dynamometer in three positions: end range ER, neutral 0°, and end range IR. Data were analyzed using a non-parametric tree based regression method (CART) and then cross-validated.

Results: The results showed that those with an increased total arc of motion of glenohumeral rotation (greater than 165.0°) had less muscle isometric muscle strength in all tests positions than those with less glenohumeral rotation.

Conclusion: Decreased force of the ER and IR muscles of the shoulder was noted in those with increased total arc glenohumeral rotation (> 165.0°), specifically those with increased glenohumeral internal rotation (> 80.0°) when compared to those with glenohumeral rotation (< 165.0°) and glenohumeral internal rotation (< 80.0°). Future studies should include more males and attempt to develop strategies to assist those with larger excursions of shoulder rotation who may be at risk of developing shoulder problems.

Level of Evidence: Level 2

Keywords: Classification and regression tree, range of motion, rotator cuff, shoulder
INTRODUCTION
Increased range of motion at the glenohumeral joint is often related to glenohumeral joint instability.\(^1\)\(^2\) When too much passive joint movement is found at a joint susceptibility to subluxation is often noted.\(^3\) A number of different common shoulder problems are related to excessive glenohumeral joint range including glenoid labrum lesions, subluxation, and dislocation.\(^1\)\(^2\)\(^4\) Cyriax notes that a joint with capsular laxity, whose stability is not under full muscular control, often displays excessive range of motion.\(^3\) The rotator cuff muscles provide dynamic stability and thus the muscular control to the glenohumeral joint diminishing the stress on the glenohumeral joint capsule and ligaments thus reducing the risk of injury.\(^5\)\(^6\) Contraction of the rotator cuff muscles tightens the joint capsule and provides compression to the joint thereby decreasing humeral head translation.\(^7\) Clinically, the stabilizing role of the rotator cuff is evident in those with rotator cuff tears where a damaged rotator cuff can contribute to glenohumeral joint instability.\(^8\) Thus assessing the total arc of glenohumeral rotation as well as the strength of the rotator cuff muscles is important to physical therapists, however, whether the two are related remains unknown.

Many researchers have examined the strength of the shoulder ER and IR muscles using isometric or isokinetic methods, however, none have looked at how strength is related to joint ROM. Few if any studies in the literature have examined whether the amount or type of glenohumeral rotation is related to the strength of the rotator cuff muscles. Specifically, could the amount of glenohumeral rotation, or total arc of motion (IR+ER) predict the strength of the rotator cuff muscles (ER and IR)? Most of the studies published have used isokinetic testing methods demonstrating similar results, mainly that the ER muscles are weaker than the IR muscles, the dominant side is stronger than non dominant side for the IR muscles (especially in athletes who regularly use one side more than the other), and women are weaker than men, but none have collected data on how rotator muscle strength relates to shoulder range of motion.\(^9\)\(^10\) Donatelli examined shoulder range of motion and strength of the ER and IR muscles in 39 professional baseball players, however in their study they did not look at how or if differences in glenohumeral rotation were related to the isometric strength of the IR or ER muscles.\(^11\) No previous study has looked at how passive shoulder range of motion (specifically glenohumeral) is related to the strength of the IR and ER muscles when divided into groups with differences in their total arc of glenohumeral rotation.

The purpose of this study was to see if total arc of rotation of the glenohumeral joint rotation (ER + IR) could predict peak isometric muscle strength of the IR or ER muscles of the shoulder. Specific questions posed included: 1) Do those who exhibit larger total arcs of glenohumeral rotation have IR or ER muscle strength differences? 2) Where in the range of motion (e.g. middle range versus end ranges of glenohumeral rotation) do the differences in ER or IR muscle strength occur? The research hypothesis for this study was that the IR and ER muscles of those with an increased total arc of shoulder glenohumeral rotation would have reduced or less isometric strength at the end range of motion of the ER and IR muscles when compared to those with subjects who did not have an increased total arc of glenohumeral rotation.

METHODS
This study represents secondary analysis of data from 53 adult participants who were recruited as part of a cross-sectional study that was previously approved by the Maryville University Institutional Review Board. The participants included a sample of convenience from Maryville students (both athletes and non-athletes) and from the surrounding St. Louis area. The sample consisted of 12 males and 41 females age 18-65 (mean age: 24.1; SD: 9.2). Forty-nine participants were right hand dominant and four were left hand dominant. Participants were asked to wear non-restrictive clothing with access to the shoulder (i.e. a loose fitting t-shirt). Exclusion criteria included: previous shoulder surgery in the past three years, shoulder pain, neck pain, arm pain, unable to tolerate the supine position, history of chronic shoulder dislocations, or current pregnancy. Participants all signed an informed consent form, filled out a questionnaire to assess if they were eligible for the study, and were then assigned a research participant number. The participant number was used to determine which muscle group would be tested first
at each position; even number participants had the ER muscles tested first, and odd numbers had the IR muscles tested first. Next, participants randomly drew cards to determine whether the right or left arm was tested to prevent the problem of statistical independence by using both shoulders in a single subject. All together 28 right shoulders and 25 left shoulders were tested. Participants then selected different cards, each with a different testing position (end range IR, end range ER, and neutral), to randomize the testing position order.

A twelve-inch plastic universal goniometer was used to measure passive shoulder IR and ER range of motion (ROM); standard error of the measure for a universal goniometer is five degrees. The ROM of shoulder (glenohumeral) rotation was measured with the participant lying supine on a standard treatment table, with the glenohumeral joint positioned at 90° of abduction for passive IR and ER measurements. Participants were first passively moved through their available shoulder rotation ROM prior to the ROM measurements, this was performed primarily to assess the participant’s ability to relax during ROM testing. Manual pressure was applied to the anterior shoulder (caracoid process) using a method described by Cibulka12 in order to prevent substitution at the sternoclavicular and acromioclavicular joints while the glenohumeral joint was rotated into the direction of IR or ER until a firm end feel was met, (Figure 1) as a firm end feel represents the end PROM for each movement about the glenohumeral joint. The goniometer was aligned as follows: the axis at the olecranon process, the stationary arm was perpendicular to the floor, and the moving arm was aligned with the ulna using the ulnar styloid process for reference. A small towel roll was placed under the participant’s distal humerus so that it remained parallel to the treatment table surface. Goniometric measures for IR and ER were measured and a different observer documented the ROM. Intra rater reliability using the intraclass correlation coefficient (ICC) was established from the first consecutive 15 participants. The ICC (3,1) for both IR and ER was found to be high, ICC = .99 [95% CI: .97-.99]. The minimal detectable change (MDC95) was determined for IR ROM (4.7°) and ER ROM (3.4°) using the formula MDC95 = SEM x 1.96 √ 2. All descriptive data for our participants ROM is displayed in Table 1.

Shoulder strength during manual muscle testing (MMT) was defined as the peak isometric force measured with a hand held dynamometer (HHD) (Hoggan Scientific, Salt Lake City, UT). Both IR and ER isometric strength was measured using a HHD by performing a “make” test of the IR and ER muscles with the participant lying supine. The two testers who performed the MMT were different from the ROM testers and were blinded from the ROM data. The “make” test using a HHD has previously been demonstrated with an ICC of .91. Participants strength was assessed in three different test positions: end range ER, neutral 0° and end range IR. The end range IR and ER positions consisted of the end of each participant’s available ROM in each direction without scapular or trunk substitutions. The glenohumeral neutral 0° position was where the participant’s forearm was placed perpendicular to the anatomical axis of the body. While supine the participant was manually placed, according to their range, in each of the different test positions prior to strength testing. The HHD was placed approximately three cm proximal to the ulnar styloid process, and in the center of the participant’s forearm, while a slight pressure was used to stabilize the anterior shoulder to prevent scapular substitution. All participants were instructed to slowly increase their force into the HHD until a maximum contraction was achieved. This maximum contraction was held for three seconds. Each participant had IR and ER isometric strength measurements taken twice at each testing position and then averaged, and the same muscle group was never assessed consecutively. To ensure data were taken in an unbiased manner, the measures were read and recorded by a separate observer. All isometric strength data was normalized to body weight by dividing muscle force in Newton’s by body weight in kg (N/kg). MDC95 for normalized ER isometric muscle force was determined using the formula MDC95 = SEM x 1.96 √ 2; MDC95 = .055 N/
kg. The MDC_{95} for normalized IR isometric muscle force was also determined; MDC_{95} = .063 N/kg.

The reliability of the “make” manual muscle tests for the first 15 participants IR and ER muscles for each of the different test positions was very high (.95-.99) (Table 2). The principal investigator did not participate in the collection of any data and was also blinded to the results until all of the data was gathered (ROM and MMT).

**Statistical Analysis**

A non-parametric classification and regression tree (CART) based method that uses a recursive partitioning process from the open source statistical package R\(^{14}\) was used to analyze the data. The CART routine begins with a binary split using a multiple regression method that looks for the greatest deviance (mean squared error) between the independent variable or predicted variable (shoulder ROM) and the predictors (either ER or IR muscle strength) to find the best fit.\(^{14}\) The CART program creates binary splits, thus always splitting the data into two groups (nodes) creating the “best” splits maximizing the difference between the two (binary) groups.\(^{15}\) The process stops when there is one observation per node (group) or the node has identical predictor variables.\(^{15}\) An advantage of using CART program is that it can specifically identify if there is a threshold or pattern of glenohumeral rotation that could predict weakness of the IR and ER muscles. A total of 6 different CART trees were modeled using shoulder strength data of the ER and IR muscles at the three different muscle test positions: end range ER, end range IR, and mid-position (0° - neutral) as the dependent variable. The independent variable was total glenohumeral rotation range of motion (IR + ER) for all six CART trees modeled. An inherent limitation of CART models is that they can have high variance, therefore, cross-validation was performed to “prune the tree” or “trim back the tree” in order to determine the best fit—followed by the use of a bootstrap procedure (1,000 resamples with replacement) to ensure data accuracy.\(^{14}\) Data were also examined by looking at the means and standard deviations by group created by the tree methods splitting at the first node. (Table 3 & 4)

### RESULTS

The results indicated that the best predictor for ER and IR muscle strength was when total shoulder rotation (ER + IR) was “split” at 165.0° creating a subgroup (N=9) who had total shoulder ROM greater than 165° and another with total shoulder ROM less than 165° (N=44), thus creating two groups. Participants with total glenohumeral rotation greater than 165.0°, regardless of whether they were tested at the end range or neutral position of external and internal rotation, had weaker ER and IR muscle force than those who had total shoulder ROM less than 165°. (Table 3 & 4)

Six females and 3 males had a total ROM (ER + IR) that exceeded 165.0° (range: 166.5-187.0°; sd = 6.8) [CI\(_{95}\) : 166.8-174.5]. The mean amount of passive ER was 91° (range: 81-110; sd = 9.8) [CI\(_{95}\) : 88.0-99.1] while

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**Table 2. Reliability (ICC’s) for IR and ER MMT for each test position.**

<table>
<thead>
<tr>
<th></th>
<th>End-range IR</th>
<th>Neutral 0°</th>
<th>End-range ER</th>
</tr>
</thead>
<tbody>
<tr>
<td>External rotator muscles</td>
<td>0.980</td>
<td>0.987</td>
<td>0.952</td>
</tr>
<tr>
<td>Internal rotator muscles</td>
<td>0.990</td>
<td>0.978</td>
<td>0.991</td>
</tr>
</tbody>
</table>

**Table 3. Mean (SD) Isometric External Rotator muscle strength in N/kg for the 2 groups.**

<table>
<thead>
<tr>
<th>Group</th>
<th>ER</th>
<th>N</th>
<th>IR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total ROM &gt; 165.0</td>
<td>.20 (.06)</td>
<td>.63 (.10)</td>
<td>.45 (.20)</td>
</tr>
<tr>
<td>Total ROM &lt; 165.0</td>
<td>.30 (.08)</td>
<td>.71 (.19)</td>
<td>.63 (.10)</td>
</tr>
</tbody>
</table>

ER = end range ER; IR = end range IR; N = Neutral 0°

**Table 4. Mean (SD) Isometric Internal Rotator muscle strength in N/kg for the 2 groups.**

<table>
<thead>
<tr>
<th>Group</th>
<th>ER</th>
<th>N</th>
<th>IR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total ROM &gt; 165.0</td>
<td>.43 (.09)</td>
<td>.54 (.10)</td>
<td>.35 (.10)</td>
</tr>
<tr>
<td>Total ROM &lt; 165.0</td>
<td>.60 (.28)</td>
<td>.61 (.21)</td>
<td>.42 (.14)</td>
</tr>
</tbody>
</table>

ER = end range ER; IR = end range IR; N = Neutral 0°
the mean amount of passive IR was 81° (range 74-88°; sd = 11.7) [CI95: 74.0-88.0]. For the 44 participants who had total shoulder ROM less than 165.0° their mean passive ER was 90° (range 60-112°; sd = 12.6) while mean passive IR was 50° (range 19-83°; sd = 13.1).

DISCUSSION

The CART analysis showed that those participants whose total arc glenohumeral rotation exceeded 165.0° both the IR and ER muscles exhibited less force production than those whose glenohumeral rotation was less than 165.0°. This was true for all test positions (end range IR, end range ER, and the neutral position). The isometric strength values exceeded minimal detectable change (MDC95) for both the ER and IR muscles in all test positions when comparing the group with greater than 165.0° of total arc of rotation with those who had less than 165.0° of rotation (Tables 3 & 4). Although the CART method established a cutoff value (165.0°) that split the groups into two, the exact break point is not the most important point, as different samples may show different cutoff points. The results of this study indicate that participants with a greater total arc of glenohumeral rotation exhibited ER and IR muscle weakness when compared to those with smaller total arc of glenohumeral rotation.

The amount of range of motion for IR and ER in the glenohumeral joint is dependent on a number of different variables including gender, dominant arm (predominantly in overhead throwers), active versus passive movement, and scapular stabilization method (for IR). Data from studies by Boon et al and Awan et al show that males have overall less total glenohumeral rotation than females, with less IR and ER motion.16,17 The data from other studies show only a small difference (most studies about 4°; less than MDC) between dominant arm versus non-dominant arm.16,18,19,17,20 However the range of motion values for glenohumeral joint rotation of overhead throwers (primarily baseball pitchers) are significantly different when comparing dominant to non-dominant side.21 In overhead throwers IR is often less than ER and with increasing age and participation the difference between IR and ER becomes greater.22,23 Often overhead throwers have a reduction in IR on the dominant shoulder side.23,25 None of the participants were involved in an overhead throwing sport (e.g. baseball) so there was no expectation to see meaningful differences between in IR and ER rotation range of motion between the dominant side and non-dominant side. In this study, however, differences due to dominance were not evaluated since only one shoulder was tested and the shoulder was randomly selected.

In this group of participants the data showed that the larger excursion in glenohumeral range of motion was perhaps due to a larger than expected amount of glenohumeral joint IR. Those with a total glenohumeral PROM greater than 165.0° had a mean IR of 81° while the mean of those with PROM less than 165.0° had a mean IR of only 50°. In a recent study that examined the quantity of shoulder rotation only 5% of the females and males had IR values greater than 80°.18 As an individual ages the total amount of glenohumeral rotation decreases,18 however in the current study only a young cohort was represented (mean age 24).

The amount of glenohumeral IR measured is dependent upon how the scapula is stabilized. Care must be taken when looking at other studies whose authors did not stabilize the scapula. Studies that do not include any scapular stabilization allow motion at the acromioclavicular and sternoclavicular joints thereby inflating the values of passive glenohumeral IR by as much as 30°.16 In this study we stabilized the scapula by firmly holding the coracoid process, using a method described by Cibulka,12 in an effort to allow only glenohumeral joint motion to occur. Data from studies that collected data on glenohumeral IR measurements using a similar cohort and stabilization method found that glenohumeral IR ROM ranged anywhere from 33° to 73° with a mean amount of passive IR about 55°.19,26,27-30

An important aim of this study was to determine whether ER and IR muscle force was different at end of range because that is where the greatest stress on joint capsule, labrum and ligaments develop and most injuries likely occur. Escamilla suggests that most shoulder injuries occur during the end phases of throwing where shoulder forces, torques and muscle activity are generally greatest during the arm cocking and arm deceleration phases of overhead throwing.31 During overhead throwing, high rotator cuff muscle activity is generated to help resist the
high shoulder distractive forces occurring during these phases. The external rotators must contract to decelerate medial shoulder rotation during the release or follow-through phase of throwing, while the internal rotators must contract to decelerate lateral rotation during the cocking phase of throwing. Previous authors have shown that isometric peak force of the shoulder ER muscles is lowest when the ER muscle's are at end range ER, and the IR muscle force production is lowest when at end range of IR. Therefore, those with larger excursions of glenohumeral rotation may be more vulnerable to throwing injuries because of weakness in their rotator cuff muscles especially end ranges of IR and ER, however future studies are needed. Physical therapists should MMT the shoulder at more than just the commonly taught standard positions to identify those who may be more vulnerable in the end ROM positions.

A nonparametric Classification and Regression Tree (CART) method was used to analyze the data. An important advantage of using the CART over standard statistical analysis is that groups of variables can be subdivided or classified into groups that reflect patterns that allow for meaningful clinical decision-making. So far many authors have examined shoulder range of rotation and isometric muscle strength but in all of these studies the data was combined into one group. Using standard statistics to examine data it is likely that meaningful information may never have been uncovered. The CART algorithm often works well because it often classifies groups into clinically important categories. In this study the binary splitting created two groups with different total arcs of glenohumeral rotation that displayed different isometric muscle strength. Without using a program like CART it would have been unlikely to uncover such differences.

This study is a preliminary study; a limitation of this study is the relatively small sample size (N = 53). Small sample sizes can lead to misclassification when using CART. To adjust for this two methods were utilized, one was to cross-validate the results (which simplified the results by pruning the branches of the tree) and secondarily, a “bootstrap” was used to resample with replacement the original data (1000 times). Using convenience sampling may also have resulted in a distorted assembly, thus replication of the study is important with future studies performed to validate this studies results. There were more females than males (41 females versus 12 males) and three males had large total glenohumeral rotation excursions compared to six females. Previous studies have found that females have a slightly larger excursion of shoulder rotation. To make sure this gender imbalance did not affect the results we modeled (CART) using female and male data separately resulting in the same cutoff threshold for total glenohumeral rotation (165.0° of total glenohumeral ROM) with a mean of IR ROM (80.0°). Furthermore to prevent the potential problem of minority outliers to bias the sample resampling was performed for the gender-separated data using the bootstrap method (resampling 1000 times) and no significant differences were found. Regardless, future studies that would replicate this study using a larger sample size are needed to substantiate this studies findings.

**CONCLUSION**

When assessing shoulder strength of the ER and IR muscles particular attention should be paid to those who have increased total arc of PROM of glenohumeral rotation (> 165.0°), especially in those with large amounts of IR ROM (80° or greater). Those with increased glenohumeral internal rotation (> 80°) generate less peak isometric IR and ER strength throughout their range of rotation than those with glenohumeral internal rotation under 80°.

**REFERENCES**


ABSTRACT

**Background:** Researchers have demonstrated moderate evidence for the use of exercise in the treatment of subacromial impingement syndrome (SAIS). Recent evidence also supports eccentric exercise for patients with lower extremity and wrist tendinopathies. However, only a few investigators have examined the effects of eccentric exercise on patients with rotator cuff tendinopathy.

**Purpose:** To compare the effectiveness of an eccentric progressive resistance exercise (PRE) intervention to a concentric PRE intervention in adults with SAIS.

**Study Design:** Randomized Clinical Trial

**Methods:** Thirty-four participants with SAIS were randomized into concentric (n = 16, mean age: 48.6 ± 14.6 years) and eccentric (n = 18, mean age: 50.1 ± 16.9 years) exercise groups. Supervised rotator cuff and scapular PRE's were performed twice a week for eight weeks. A daily home program of shoulder stretching and active range of motion (AROM) exercises was performed by both groups. The outcome measures of the Disabilities of the Arm, Shoulder, and Hand (DASH) score, pain-free arm scapular plane elevation AROM, pain-free shoulder abduction and external rotation (ER) strength were assessed at baseline, week five, and week eight of the study.

**Results:** Four separate 2x3 ANOVAs with repeated measures showed no significant difference in any outcome measure between the two groups over time. However, all participants made significant improvements in all outcome measures from baseline to week five ($p < 0.0125$). Significant improvements also were found from week five to week eight ($p < 0.0125$) for all outcome measures except scapular plane elevation AROM.

**Conclusion:** Both eccentric and concentric PRE programs resulted in improved function, AROM, and strength in patients with SAIS. However, no difference was found between the two exercise modes, suggesting that therapists may use exercises that utilize either exercise mode in their treatment of SAIS.

**Level of evidence:** Therapy, level 1b

**Key Words:** Physical therapy, rotator cuff, shoulder, strengthening

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INTRODUCTION
Disorders of the shoulder complex; which includes the clavicular, scapulothoracic, and glenohumeral articulations, have been suggested to be the third most common cause of musculoskeletal consultation in primary care with the most common shoulder diagnosis being subacromial impingement syndrome (SAIS).1-3 Moderate evidence supports the use of therapeutic exercise in the treatment of SAIS.4-8 More specifically, the results of exercise intervention studies targeting the rotator cuff and scapular muscles demonstrate significant pain reduction and functional improvement in the short term, as well as functional improvement in the long term in patients with SAIS.7,9,10 However, these studies of interventions for SAIS have used a wide variety of types and modes of exercises, mostly using concentric and eccentric contractions with elastic bands, machine weights, and free weights.11-16 Furthermore, the authors of those studies compared their exercise programs to other treatment modalities such as injections, surgery, and manual therapy or have compared supervised versus home exercises programs, but none compared types of resistive exercises to determine which is most effective in the treatment of SAIS.

Studies of rotator cuff and knee extensor muscles in asymptomatic individuals and rat tendons have demonstrated greater cross-sectional area, increased fascicle length, greater neuromuscular activation, greater strength and peak torque, increased tendon collagen synthesis, and stabilization of angiogenesis with eccentric exercise.17-23 Based on these findings, clinicians are increasing their use of eccentric exercise in the treatment of tendinopathies. Recent studies by investigators who have used eccentric exercise in treatment of Achilles, patellar and wrist extensor tendinopathy have demonstrated greater pain reduction and improvement of function than concentric exercise.24-28 Three case series have been performed that examine the effect of eccentric exercise on patients with SAIS and have shown favorable outcomes, such as pain reduction and functional improvement when the eccentric exercises were included in the treatment plan.29-31 Furthermore, Maenhout et al found increased shoulder abduction strength when adding an eccentric full can exercise to concentric-eccentric internal and external rotation (ER) exercises in a randomized clinical trial (RCT). However, no additional benefit was found for pain reduction or functional improvement.32 To the authors’ knowledge, no studies specifically have compared concentric and eccentric exercises in patients with SAIS. Therefore, the purpose of this study was to compare the effectiveness of an eccentric progressive resistance exercise (PRE) intervention to a concentric PRE interventions in adults with SAIS.

METHODS
Participants
An a-priori power analysis was conducted using G*Power version 3.1.2 to estimate the sample size required to find statistically significant differences with a desired level of power set at 0.80 and an α-level at 0.0125.33 Effect sizes of 0.55 to 1.06 were found in previous studies that investigated shoulder function using the Disabilities of the Arm, Shoulder, and Hand (DASH) as an outcome measure in persons with adhesive capsulitis, post acromioplasty, and impingement.34-36 However, a medium effect size of 0.25 was used for this study as a conservative estimate because the current study protocol included two exercise interventions and had no true control group which would likely result in a smaller effect size. An estimate of 38 participants, 19 participants per group, was required to ensure adequate power for an ANOVA with repeated measures.

Fifty-five patients who were at least 18 years old and who had shoulder pain were recruited for this study from an urban, hospital-based, outpatient rehabilitation center. Once patients agreed to participate in the study, they were asked to read and sign an informed consent in accordance with Institutional Review Board (IRB) requirements. Participants were excluded if they had a history of shoulder, cervical, or thoracic surgery, shoulder dislocation, fracture, labral tear, full-thickness rotator cuff tear, adhesive capsulitis, rheumatic disease, pregnancy or medical condition that precluded them from performing resisted exercises. Participants who had pain level at or higher than 7/10 on the numeric pain rating scale (NPRS) were excluded from the study as this level of pain indicated a shoulder condition not likely
to respond to exercise alone. Screening evaluation was performed by the primary investigator (PI), a licensed physical therapist and orthopaedic clinical specialist with over 22 years of experience. The screening evaluation included the Neer, Hawkins-Kennedy, and coracoid (i.e. cross-body) adduction impingement tests to confirm their impingement symptoms. The infraspinatus test, drop arm test, and “empty can” tests were used to rule out patients with a full thickness rotator cuff tear. Eligible participants were the patients who had at least one positive impingement test and one negative rotator cuff tear test. Participants with three positive rotator cuff tear tests were likely to have a full-thickness rotator cuff tear, and were excluded from the study. After the screening examination, 38 out of 55 participants were eligible for the study.

Examiners and Treating Therapist
Seven examiners participated in the collection of outcome measurements. The examiners included four licensed physical therapists, two second-year physical therapy doctoral students, and one licensed occupational therapist. The licensed clinicians averaged over 20 years of experience and included two certified hand therapists and two doctors of physical therapy. Prior to data collection, the PI met with the examiners and familiarized them with the testing protocol. The PI was the treating physical therapist for all participants.

Outcome Measures
Once participants were determined to be eligible for the study, they underwent a baseline outcome measure assessment. The baseline and follow-up outcome measurements were assessed by an examiner who was blinded to the treatment group. The same examiner performed three testing sessions with each participant; at baseline, at week five, and at week eight. Participants were asked to stop taking pain medication four hours prior to their appointment on outcome assessment days to ensure accurate assessment of their pain-free range of motion and strength. However, participants could take their pain medications as prescribed by their physician at all other times during the study. Each participant completed a baseline NPRS rating and the DASH functional outcome measure. As shown in Figure 1, participants also were assessed for pain-free AROM of arm elevation in the scapular plane using a digital inclinometer in sitting following the method described by Kolber et al. Two trials of AROM measurements were recorded and the mean value of the two measurements was used for data analysis.

Isometric strength for shoulder abduction and ER was assessed using an Accuforce Cadet hand-held dynamometer (HHD) (Ametek Incorporated M & G Division, Largo, Florida). Both motions were tested in supine to minimize the effect of differing limb weight of participants. Abduction and ER were tested with the shoulder in 90° of abduction and 90° of elbow flexion. Resistance was applied perpendicular to the distal humerus just above the lateral epicondyle for abduction and perpendicular to the dorsal distal forearm one inch proximal to the ulnar styloid for ER (Figures 2 and 3). Participants held the aforementioned positions as the examiner applied force through the dynamometer using the “make” test procedure with the participant building up to maximal tension in one to two seconds and continuing to maintain the tension for four to five more seconds. Two measurements were taken for each of the two strength tests, with a 30-second rest between the two measurements to allow for muscle recovery.
The mean of the two measurements of each strength test was used for data analysis. The length of the limb from the lateral edge of the acromion to the lateral epicondyle and from one inch proximal to the ulnar styloid to the proximal olecranon was also recorded for calculating torque (N·m). The four outcome measurements (DASH score, AROM of scapular plane elevation, shoulder abduction strength and shoulder ER strength) were performed again at the end of five and eight weeks of the supervised interventions.

**Participant Allocation**

Once the baseline outcome measurements were completed, participants were randomly assigned to one of the two intervention groups using pre-prepared, sealed folders. Figure 4 illustrates the CONSORT diagram for participant recruitment, randomization and enrollment. One enrolled participant in the concentric group dropped out at three weeks due to an unrelated medical issue and was not included in the data analysis. Three additional participants in the concentric group withdrew after five weeks, one due to traveling out of state and two for financial and work conflict reasons. As a result, a total of 34 (91%) of the participants completed the 8-week study and the final assessments, 16 in the concentric group and 18 in the eccentric group. An intention-to-treat analysis using the last observation carried forward method was performed for statistical analysis.

**Interventions**

Both groups of participants completed a supervised PRE program two times a week for eight weeks. The first two weeks of the intervention involved both groups being familiarized with the exercise techniques and equipment, as well as a submaximal repetition maximum (RM) testing procedure in order to determine the resistance to be used during exercise sessions. Familiarization involved two sessions of instruction and performance of each exercise with a light resistance that did not cause pain and instruction by the PI in correct exercise technique in pain-free ROM. The third week began the differentiation of treatment intervention of the eccentric and concentric intervention groups using the resistance predicted by the submaximal RM testing. Figure 5 illustrates the timing and flow of the exercise program and assessment sessions. Participants were instructed to perform only the exercises given as part of the study intervention and to avoid adding any new upper body activities until completion of the study. Participants also were informed that they were not to receive any other therapy or treatment for the involved shoulder during the study period.

The exercises used in this study were chosen based on literature review of electromyographic (EMG) and biomechanical studies of exercises that optimize rotator cuff and scapular muscle recruitment. The exercises included the seated “full can”, sidelying internal rotation (IR), sidelying ER with towel...
roll, supine protraction, sidelying horizontal abduction, sidelying abduction, and prone shoulder extension in neutral rotation. All exercises (Appendix 1) were performed using a dumbbell, and were performed in the participant's pain-free AROM. The eccentric exercise group performed the lowering portion of the exercises with the therapist repositioning the weight to the starting position to avoid resistance during the lifting (concentric) portion of each exercise. The concentric group performed the lifting portion of the exercises with the therapist repositioning the weight to the start position to avoid resistance in the lowering (eccentric) portion of the exercise. The PI was the treating physical therapist for all participants and was not involved in the outcome measure assessment in order to prevent bias of the results. Participant in both groups were given a home exercise program (HEP), consisting of pectoralis minor and posterior shoulder stretching, thoracic spine self-mobilization into extension, and pain-free AROM in flexion and abduction standing in front of a mirror to monitor for excessive scapular elevation.

The primary purpose of the HEP was to address the soft tissue, joint, and capsular tightness commonly cited for contributing to poor scapular and glenohumeral biomechanics.46 Participants were asked to perform the HEP once daily on the days they did not exercise in the clinic, as well as part of the cool down exercises after clinic exercise sessions. In addition, participants were asked to keep an exercise log of their HEP performance, which was reviewed by the treating therapist at the end of each week to monitor compliance. This log was turned in at the completion of the study.

Repetition maximum assessment

The repetition maximum (RM) assessment was used to standardize the procedure for determining an appropriate weight for our participants' shoulder exercises. Because the study participants had shoulder pain and pathology a submaximal 20RM testing procedure was used in order to minimize strain on...
the injured shoulder but still arrive at an appropriate exercise dosage using a standardized method. The commonly used 1 RM testing for healthy athletes would not be appropriate to use in patients with painful shoulders. Research has shown that the majority of injuries occur during the 1RM testing, not the PRE program itself. In order to reduce the risk of injury during RM testing, it has been suggested that the actual 1RM be predicted using an equation established from submaximal RM testing. In addition, it has been shown that older adults and novice exercisers require multiple assessments of the RM in order to obtain an accurate assessment. Therefore, participants in the current study underwent the 20RM testing procedure twice in week two. The better of the two 1RM predictions was used to determine the training resistance.

During the 20RM testing, the treating therapist initially selected a resistance that they anticipated would result in the participant's inability to lift with correct form or "fail" between 10 and 20 repetitions. This resistance selection was informed by the therapist's observation of the participant's exercise technique and muscle control during the familiarization sessions of week one. If the participant completed more than 20 repetitions at the chosen resistance, maintaining a speed of two to four seconds to lift and to lower, they rested for four minutes before trying again with a heavier resistance. The number of
repetitions completed in the “failure” set was used in the Kemmler, Lauber, Wassermann (KLW) formula to predict the 1RM for each exercise. The KLW formula is \( wi [0.988 - 0.0000584 ri^3 + 0.00190 ri^2 + 0.0104 ri] \) where \( wi \) is the load of measurement, and \( ri \) is the number of repetitions. This formula was shown to be an accurate predictor of 1RM across a number of repetitions up to 20. For each submaximal 20RM testing, a warm-up consisting of five minutes on the UBE followed by one set of ten repetitions at 50% of the testing resistance was performed prior to the first testing trial for each exercise.

**Exercise Progression**

During the first session of week three, participants were instructed in the respective group exercises: either the concentric or eccentric portion of the training exercises. Both groups performed three sets of 12 repetitions of each of the seven intervention exercises at 70% of their newly predicted 1RM. Figure 5 illustrates the resistance training protocol and progression for each week of the study. If the training weight predicted by the formula fell between the dumbbell increments available in the clinic, the resistance was rounded down to the next closest dumbbell weight. Because the outcome assessments occurred again in the fifth and eighth week from enrollment, the submaximal 20RM testing was repeated at week four and at week six. Training resistance was adjusted in the sessions following the exercise testing sessions with participants performing three sets of 12 repetitions using resistance of 70% of the new predicted 1RM. In the week immediately prior to the next exercise testing session, the resistance was increased to 80% of the predicted 1RM.
STATISTICAL METHODS
The collected data was analyzed using SPSS Graduate Pack 22.0 (IBM Corp., Armonk, New York). Descriptive statistics were performed to illustrate the participant characteristics of gender, age, baseline DASH scores, baseline pain severity level, and duration of symptoms. Baseline age, DASH score, pain severity level, AROM, strength measurements and duration of symptoms were analyzed using t-tests ($p = 0.05$) to determine if differences between the groups existed. Four separate 2x3 analyses of variance (ANOVA) with repeated measures were used to compare each of the four dependent variables between the groups at baseline, and after five weeks and eight weeks of exercise intervention. The $\alpha$ was set at 0.0125 after the adjustment for each ANOVA to minimize type I errors. Post hoc comparisons ($p = 0.05$) were performed when a significant difference was found.

RESULTS
Table 1 summarizes the characteristics of the participants in each group at baseline. The mean age for all participants was near 50 years with a range of 23 to 84 years. The mean symptom duration was just under two years. Baseline shoulder pain levels for all participants demonstrated a mean of 2.0 on the NPRS. Independent $t$-tests performed on the baseline outcome measures, and the participants’ age and duration of symptoms data revealed no significant differences between the groups. The descriptive data for the outcome measures of DASH score, pain-free scapular elevation AROM, pain-free abduction torque, and pain-free ER torque are presented in Table 2. The mean DASH score at baseline for all participants was 23.2 with the mean score improving in each of the subsequent time frames. Mean scaption AROM for all participants was 120 degrees indicating limited motion. The eight week mean improved to a functional 145 degrees. Abduction torque for all participants started at a mean of 18.7 N.m for all participants and increased to a mean of 29.2 N.m at the end of the eight week intervention. Similarly, the ER torque for all participants improved from a mean at baseline of 12.8 N.m to a mean of 21.2 N.m by the end of the intervention. The results of the ANOVAs showed no significant interaction of treatment group by time for all outcome measures: (a) DASH score ($p = 0.890$), (b) arm elevation AROM ($p = 0.373$), (c) abduction torque ($p = 0.421$), and (d) ER torque ($p = 0.933$). The main effect of time was significant for all four outcome measures ($p < 0.001$). Post-hoc analyses revealed significant improvements for all of the

| Table 1. Participant Characteristics and Outcome Measurements at Baseline |
|-----------------------------|-----------------------------|-----------------------------|
|                             | Concentric Exercise (n=16)  | Eccentric Exercise (n=18)   | All (n=34)         |
| Gender (M/F)                | 6/10                        | 8/10                        | 14/20             |
| Age (years)                 | 48.6 ± 14.6                 | 50.1 ± 16.9                 | 49.4 ± 15.6       |
| Involved shoulder (R/L)     | 7/9                         | 11/7                        | 18/16             |
| Duration of symptoms (months) | 20.6 ± 26.6                | 28.2 ± 23.6                 | 22.7 ± 24.3       |
| NPRS score                  | 2.1 ± 1.6                   | 2.0 ± 1.8                   | 2.0 ± 1.7         |
| DASH score                  | 21.2 ± 6.5                  | 25.0 ± 10.6                 | 23.2 ± 9.0        |
| Scapular elevation AROM (°) | 125.0 ± 35.8                | 114.8 ± 37.5                | 119.6 ± 36.5      |
| Shoulder abduction torque (N.m) | 17.9 ± 11.7                | 19.5 ± 12.4                 | 18.7 ± 11.9       |
| Shoulder ER torque (N.m)    | 11.1 ± 10.3                 | 14.4 ± 11.0                 | 12.8 ± 10.6       |

Abbreviations: M= male; F= female; NPRS= Numeric Pain Rating Scale; DASH= Disabilities of the Arm, Shoulder, and Hand; AROM= active range of motion; ER=external rotation
reported for eccentric exercise when eccentric exercise was used in the treatment of tendinopathy of the Achilles, patellar, and wrist extensor tendons. The aforementioned studies only assessed pain intensity and self-reported functional level, but did not assess strength or ROM. In addition, the eccentric exercises in the Achilles and patellar tendon studies were performed daily into the painful ROM and using body weight resistance on a single limb. One wrist extensor study used isokinetic exercises and another released a twisted rubber bar. Therefore, a direct comparison could not be made as the exercise intensity, load, and frequency used in these studies were different from those used in the current study. Maenhout et al. reported better shoulder abduction strength in the eccentric group after 12 weeks of intervention. However, similar to the findings of the current study, Maenhout et al. did not find a significant difference in functional scores using the Shoulder Pain and Disability Index (SPADI). The difference in exercise resistance level and number of different eccentric exercises performed could account for the different outcomes from baseline to week five ($p < 0.05$), regardless of group assignment. All outcome measures except arm elevation AROM ($p = 0.302$) continued to show significant improvement from week five to week eight ($p < 0.05$). Figure 6 illustrates the results collected at baseline, week five and week eight for each of the four outcome measures.

**DISCUSSION**

The results of this study revealed that there were no significant differences between the groups in strength, range of motion, or DASH scores, indicating that eccentric-based exercises were not more effective than concentric-based exercises for treating patients with SAIS. The results also revealed that the effect sizes were small for all four outcome measures: (a) DASH partial $\eta^2 = 0.002$, (b) arm elevation ROM partial $\eta^2 = 0.024$ (c) abduction torque partial $\eta^2 = 0.030$ and (d) ER torque partial $\eta^2 = 0.003$. These small values of effect size can be attributed to the lack of differences between the groups. These findings are contrary to the better outcomes that have been reported for eccentric exercise when eccentric exercise was used in the treatment of tendinopathy of the Achilles, patellar, and wrist extensor tendons. The aforementioned studies only assessed pain intensity and self-reported functional level, but did not assess strength or ROM. In addition, the eccentric exercises in the Achilles and patellar tendon studies were performed daily into the painful ROM and using body weight resistance on a single limb. One wrist extensor study used isokinetic exercises and another released a twisted rubber bar. Therefore, a direct comparison could not be made as the exercise intensity, load, and frequency used in these studies were different from those used in the current study. Maenhout et al. reported better shoulder abduction strength in the eccentric group after 12 weeks of intervention. However, similar to the findings of the current study, Maenhout et al. did not find a significant difference in functional scores using the Shoulder Pain and Disability Index (SPADI). The difference in exercise resistance level and number of different eccentric exercises performed could account for the different

**Table 2. Outcome Measurements at Baseline, Week 5, and Week 8 assessments**

<table>
<thead>
<tr>
<th></th>
<th>All (n = 34)</th>
<th>Concentric Exercise Group (n = 16)</th>
<th>Eccentric Exercise Group (n = 18)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DASH</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>23.2 ± 9.0</td>
<td>21.2 ± 6.5</td>
<td>25.0 ± 10.6</td>
</tr>
<tr>
<td>Week 5</td>
<td>13.8 ± 8.1</td>
<td>12.3 ± 7.1</td>
<td>15.1 ± 8.9</td>
</tr>
<tr>
<td>Week 8</td>
<td>10.8 ± 9.8</td>
<td>9.3 ± 7.1</td>
<td>12.1 ± 11.7</td>
</tr>
<tr>
<td><strong>Scapular elevation AROM (°)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>119.6 ± 36.5</td>
<td>125.0 ± 35.8</td>
<td>114.8 ± 37.5</td>
</tr>
<tr>
<td>Week 5</td>
<td>142.4 ± 23.5</td>
<td>142.9 ± 23.6</td>
<td>142.1 ± 24.1</td>
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<tr>
<td>Week 8</td>
<td>145.0 ± 26.3</td>
<td>143.8 ± 30.4</td>
<td>146.2 ± 23.0</td>
</tr>
<tr>
<td><strong>Abduction torque (N·m)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>18.7 ± 11.9</td>
<td>17.9 ± 11.7</td>
<td>19.5 ± 12.4</td>
</tr>
<tr>
<td>Week 5</td>
<td>23.8 ± 13.9</td>
<td>20.6 ± 12.5</td>
<td>26.5 ± 14.7</td>
</tr>
<tr>
<td>Week 8</td>
<td>29.2 ± 17.2</td>
<td>27.0 ± 16.1</td>
<td>31.2 ± 18.3</td>
</tr>
<tr>
<td><strong>ER torque (N·m)</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>12.8 ± 10.6</td>
<td>11.1 ± 10.3</td>
<td>14.4 ± 11.0</td>
</tr>
<tr>
<td>Week 5</td>
<td>17.2 ± 12.5</td>
<td>15.0 ± 11.2</td>
<td>19.1 ± 13.5</td>
</tr>
<tr>
<td>Week 8</td>
<td>21.2 ± 13.4</td>
<td>19.4 ± 13.6</td>
<td>22.7 ± 13.4</td>
</tr>
</tbody>
</table>

**Abbreviations:** DASH, Disabilities of the Arm, Shoulder, and Hand; AROM, active range of motion; ER, external rotation
findings in group strength differences between the current study and the Maenhout et al study.32

The resistance load and volume of exercise in the current study was the same for both groups in terms of percentage of predicted 1RM used and number of sets and repetitions performed. Submaximal eccentric resistance (70-80% of predicted concentric 1RM) was used to lessen the possibility of pain or injury during exercise in the participants. As a result, the concentric group may have been challenged at a different intensity than the eccentric group, as 70% of the concentric 1RM could have been easier to lower than to lift. Eccentric exercise in the training of healthy adults often involves supramaximal resistance in order to elicit muscle strength and mass gains.23 Many studies of eccentric exercise effects in other tendinopathies have used resistance that placed participants above the pain threshold.31,57,60 This approach is thought to have a greater effect on tendon properties and healing. However, the use of exercise beyond the pain threshold and use of supra-

Figure 6. Outcome measure result graphs for all participants at baseline, week 5 and week 8
maximal resistance are not feasible or reasonable for patients who have painful shoulders. Investigators who have examined the effects of eccentric exercise on muscles and tendons most recently suggest that the changes in the tissues are mainly due to resistance training load and intensity rather than contraction type, thus challenging the clinical belief in the superiority of eccentric training over concentric training. Future studies should compare similar exercise loads and intensities of the same contraction type and match intensity levels of concentric and eccentric exercises more closely in order to obtain a better comparison.

The results of this study demonstrated a significant main effect of time on all four outcome measures, indicating that all participants (both groups) made significant improvements after eight weeks for all of the outcome measures. These findings agree with the findings of the other authors who used resistance exercise in the treatment of SAIS that resulted in improved function and improved strength. Post-hoc analysis also revealed that all of the outcome measures demonstrated significant improvement from baseline to week five with the greatest change in scapular elevation AROM and function (DASH scores) occurring in that time frame. The mean improvement in the DASH scores exceeded the minimal clinically important difference (MCID) of 10 points by the week five assessment with only an additional three points improvement at week eight. From week five to week eight, all participants continued to make significant improvements in all outcome measures except scapular elevation AROM. The findings of this study suggest that significant ROM and functional improvements occurred primarily in the first five weeks of PRE treatment approaching normal limits in that time frame. Strength gains improved in that same five week time frame but continued to improve even after ROM and functional scores were no longer improving significantly. However, without a true control group, one cannot be certain if these improvements were due to our intervention or simply due to the normal course of the condition over time.

The use of a submaximal exercise testing protocol appears to be a safe method for selecting and progressing resistance for shoulder rehabilitation exercises. Many of the participants in this study were older adults who had no experience with resisted exercises. The inclusion of two sessions for exercise technique instruction and practice with light resistance prior to exercise testing resulted in no injury from exercise testing, indicating that submaximal RM testing could allow therapists to safely predict each individual's 1RM for each exercise. The prediction formula and procedures used in this study could provide a standardized approach for determining a starting resistance when patients with SAIS are ready for PRE exercises. In addition, this process of standardized exercise progression resulted in significant strength gains without increasing pain or causing injury. The methods used in the current study demonstrated appropriate exercise dosing to accomplish meaningful strength and functional gains in an efficient amount of time for patients with SAIS.

**Limitations**

There were several limitations in this study that may have impacted the findings. The use of dumbbell resistance as opposed to isokinetic resistance for the exercise intervention may have obscured significant differences in the outcome measures between the groups due to the inability to separate the concentric and eccentric phases as completely as one can with isokinetic exercise equipment. While the treating physical therapist in this study made every effort to isolate concentric or eccentric contractions performed by participants, it was not possible to completely prevent the participant from contracting their muscles or “helping” to perform the opposing contraction type during an isotonic free-weight exercise. The intention of the current study was to develop an exercise program that can be used in any physical therapy clinic with equipment commonly found in the majority of facilities. Isokinetic equipment is more feasible for studies conducted in research facilities and is cost prohibitive for many small community physical therapy facilities. Several EMG studies have indicated that sidelying exercises actually showed greater recruitment of rotator cuff muscles with less recruitment of the deltoid and upper trapezius than prone lying exercises. The side-lying position was used in this study for horizontal abduction and external rotation as a result of the findings of the EMG studies and because the older patient population in the current
study had difficulty obtaining the prone position and stabilizing the trunk against a long resistance lever with prone exercises. The use of sidelying exercises for these motions may have impacted the recruitment of the midscapular and posterior rotator cuff muscles. Another limitation of this study was lack of a true control group that did not receive an intervention, thus it cannot be determined how much of the improvement in function, AROM, and strength of the shoulders in persons with SAIS was due to the natural course of the condition or due to the treatment interventions. Because the participants were referred to the clinic for treatment, it was not ethical to withhold treatment.

Conclusion
Both submaximal eccentric and concentric PREs resulted in improved function, AROM, and strength in patients with SAIS. However, no difference was found between the two exercise modes, suggesting that therapists may use exercises that utilize either exercise mode in their treatment of SAIS.

REFERENCES


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APPENDIX 1
Figures of Exercises used during interventions

Protraction  External Rotation  Internal rotation

Sidelying Abduction  Sidelying Horizontal Abduction

Full can  Prone Extension
ABSTRACT

Background: Clinical investigation of shoulder injuries commonly utilizes visual evaluation of scapular movement to determine if abnormal or asymmetrical movements are related to the injury. To date, the intrarater reliability and diagnostic accuracy of visual evaluation of scapular movement among physical therapists are not known.

Purpose: The aims of this study were to determine the clinical reliability and diagnostic accuracy of physical therapists visual evaluation of scapulohumeral movements when used to diagnose shoulder impairment.

Study Design: University based laboratory and an internet based survey.

Methods: Thirty-three physical therapists and 12 patient participants participated in this study. Reliability was measured as percent agreement and using the free marginal kappa statistic ($\kappa$) and Cronbach’s alpha ($\alpha$) for interrater and intrarater reliability respectively. Diagnostic accuracy variables such as sensitivity, specificity, likelihood ratios were calculated from contingency table analysis.

Results: Visual evaluation yielded the following (95% CI): diagnostic accuracy 49.5%, specificity 60% (56 – 64), and sensitivity 35% (29 – 41), positive and negative likelihood ratios were 0.87 (0.66 – 1.14) and 1.09 (0.92 – 1.27) respectively. Percent agreements of evaluation findings between sessions for static and dynamic symmetry were 69% and 68%, respectively. The alpha statistics for static and dynamic symmetry were both 0.51. Percentage agreement in determining the injured shoulder was 59%, with an alpha statistic of 0.35.

Conclusion: Visual evaluation of scapular movements, without additional clinical information, demonstrated a poor to fair reliability and poor to fair diagnostic accuracy.

Clinical Relevance: The clinical utility of the use of isolated visual scapular evaluation is cautioned. More reliable and valid objective measures are needed for diagnosing shoulder impairment.

Level of Evidence: 2b, Exploratory cohort study

Keywords: Diagnostic accuracy, reliability, scapulohumeral rhythm, shoulder examination
INTRODUCTION
Visual evaluation of scapular position and movement patterns is often advocated as part of the clinical examination process of individuals presenting with shoulder girdle injury. Deviation in expected movements of the scapula is commonly referred to as scapular dyskinesis and has been related to shoulder pain, abnormal muscle activation of scapular or humeral muscles, neurological insult, shortened pectoralis minor muscle length, and history of participation in throwing sports, as well as other conditions. Scapular dyskinesis has been reported to occur in as many as 68-100 percent of patients being treated for a variety of shoulder injuries. However, variability of scapular movements is commonplace with no specific abnormal scapular movement pattern linked to specific shoulder injuries.

Several prior investigations have attempted to quantify the interrater reliability of physical therapist visual scapular movement assessment with reliability coefficients ranging from 0.08 - 0.78. This wide range of interrater reliability likely has many factors including clinician experience, differing planes of movement, load conditions (weighted or unweighted during elevation), injury type, patient characteristics, operational definitions of scapular movements and whether viewing in vivo or on video. Only one prior study has compared intrarater reliability of scapular movement patterns and the authors found moderate agreement levels (kappa scores, \( \kappa = 49 - 59 \)).

Furthermore, the diagnostic accuracy of visual scapulohumeral assessment has been studied sparingly of which only one prior study has presented sensitivity and specificity characteristics. Uhl and colleagues have reported sensitivity values of 74-78% with specificity measures ranging from 31-38% for visual accuracy compared to three dimensional kinematic data for humeral elevation into the sagittal and scapular planes. This investigation compared the ability of two clinicians specializing in shoulder dysfunction (one physical therapist and one physician) to determine whether scapular movement was normal or dysrhythmic.

The limited data available regarding intrarater reliability and diagnostic accuracy of visual scapulohumeral assessment findings indicated the need for greater investigation of such measures. Thus, the aims of this study were to determine the clinical reliability and diagnostic accuracy of physical therapists visual evaluation of scapulohumeral movements when used to diagnose shoulder impairment.

METHODS
Participants
Visual scapular evaluation was assessed via an internet-based (www.surveygizmo.com) survey on 12 patients by 33 physical therapists. The participants consisted of six patients currently being treated for unilateral shoulder impairment with a score of ≥10 on the Shoulder Pain and Disability Index (SPADI). An additional six individuals with no prior history of shoulder pathology or pain in the shoulder or neck region during the previous six months were used as a healthy control group. Therapists were blinded to the proportion of injured and control participants included in the patient group. The inclusion criteria for this study were: aged over 18 years old, demonstrated full active shoulder elevation (>150°) in the scapular plane and reported no history of upper limb surgery. The exclusion criteria indicated that no throwing athletes were permitted in the control group due to reported scapular kinematic changes in this group. Throwing athletes were permitted in shoulder impaired group if the injury was on the involved shoulder as dyskinesis is often based on bilateral comparison.

Patients with shoulder impairments were recruited from local physical therapy clinics. Control participants were recruited from local physical therapy clinics where they were being treated for impairments in other anatomic areas (e.g. knee) and from local advertisements. Physical therapists were recruited from attendees at conferences and by word of mouth. Recruitment for patient participants occurred during the spring of 2012. Participating physical therapists completed the surveys in the summer of 2012 through early 2013. All participants and physical therapists provided informed consent prior to participation in accordance with East Tennessee State University guidelines which approved this study. The rights of all participants were protected.

Surveys
Physical therapists were provided access to a secure internet based survey which contained posteriorly...
oriented still photos of patient participants in the anatomic position and videos of participants' dynamic scapulohumeral movements during humeral elevation in the scapular plane. The rate of humeral elevation was normalized at 0.5Hz per motion using a metronome. Thus, participants went from resting position to full active elevation over a two-second time frame and returned in the same time frame. A brief video describing scapular kinematics was viewed by all participants prior to completing the first survey. In an attempt to replicate clinical practice operational definitions of scapular symmetry were not provided. No additional clinical information regarding the participants in the videos was provided. The survey questions (Table 1) were logic based, thus, the sequence of questions was based on responses to prior questions in the survey. Therefore not all questions were asked of all therapists. The number of questions was dependent on the response to prior questions.

All physical therapists were requested to complete the surveys independently. A second survey containing the same pictures and videos was sent to all therapists who completed the first survey at least 48 hours after completing the first survey to determine day to day agreement. The order of the participants on the second survey was reorganized to limit recall of answers from the first survey. Similar to clinical practice, physical therapists were instructed to view the videos as many times as needed to complete the questions on the survey (including pausing and resuming as needed). All videos were viewed in real time, as no slow motion was available.

**Data Analysis**

**Diagnostic Accuracy**

Data was analyzed using a 2x2 contingency table. Sensitivity, specificity, positive and negative likelihood ratios with 95% confidence intervals were calculated. Diagnostic accuracy was calculated as a percentage correct classified as injured or healthy and via Cronbach's alpha (\(\alpha\)). Scores range from 0-100 with higher values indicating the physical therapists determination of impairment agreed with those seeking treatment for their shoulder. The reference standard for shoulder impairment was defined as those patients currently seeking treatment for unilateral shoulder impairment. This reference standard was chosen as visual evaluation is advocated for evaluating such patients.

**Reliability**

Reliability between therapists was calculated as a percentage and using a free marginal kappa statistic (\(\kappa\)) for all 33 therapists. The free marginal \(\kappa\) statistic is used for groups of participants when the number of assignments per group is not mandated, e.g. the therapists were not forced to assign \(X\) number of participants as injured. Chronbach's alpha (\(\alpha\)) was used to quantify test-retest reliability for the 30 therapists who completed both versions of the survey. Both \(\alpha\) and \(\kappa\) are scaled from 0-100. Scores close to 100 indicate higher levels of agreement for both statistics. SPSS version 21.0 (SPSS Inc, Chicago, IL) was used to calculate interrater reliability. An online kappa calculator was used to measure \(\kappa\) statistics for intrarater reliability.

**RESULTS**

**Participants**

Thirty-three physical therapists completed the first version of the survey; 30 of the 33 completed the second version of the survey. Of the 33 participants 16 had additional training or certification such as sports or orthopaedic clinical specialization, manual therapy certification, or advanced degree (tDPT or PhD). The physical therapists averaged 6.8 years of ortho-

<table>
<thead>
<tr>
<th>Table 1. Questions Completed by Physical Therapists on the Survey</th>
<th>Response Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Questions</td>
<td></td>
</tr>
<tr>
<td>Does the static scapular position of patient exhibit symmetry?</td>
<td>Yes, No</td>
</tr>
<tr>
<td>Do you believe the scapulohumeral movements of this patient demonstrate symmetry?</td>
<td>Yes, No</td>
</tr>
<tr>
<td>Which shoulder demonstrates a variation from symmetry?</td>
<td>Right, Left</td>
</tr>
<tr>
<td>Do you believe this patient has a symptomatic shoulder?</td>
<td>Yes, No</td>
</tr>
<tr>
<td>Which shoulder do you consider to be symptomatic?</td>
<td>Right, Left</td>
</tr>
</tbody>
</table>
paedic clinical experience (range 1-28). Only surveys that were fully completed were used for analysis.

As noted above, 12 video participants were included in the study with demographic info in Table 2. All shoulder-injured participants were right hand dominant, and four of the participants in the control group were right hand dominant. The right shoulder was injured in four participants in the shoulder-impaired group. One of the participants in the shoulder-impaired group was a throwing athlete whose injury was the throwing shoulder. The shoulder impaired group consisted of three females, the control group had four females.

**Diagnostic Accuracy**

The sensitivity of visual scapular assessment in this study was 34.7% (95% CI: 29-41). Specificity was 59.9% (95% CI: 56-64). The positive likelihood ratio was 0.87 (95% CI: 0.66-1.14) and the negative likelihood ratio was 1.09 (95% CI: 0.92-1.27). The overall diagnostic accuracy, indicated by the percent correctly identified as positive and negative for current treatment, was 49.5%. When chance correct answers were accounted for, was 37.5% in determining if the participants had an injured shoulder and 35.3% for correctly choosing the impaired side. The number needed to diagnose (NND) was 20, which indicates that the test would be accurate for every 1 out of 20 patients on whom it is performed.

**Reliability**

Reliability was poor to fair both between therapists (κ range: 15.5 - 25.5) and for test-retest (α range: 35.3 - 51.34) (Table 4).

**DISCUSSION**

The results of this study indicate the ability of physical therapists to utilize information gleaned solely from static photos and video recordings of scapular movement patterns to classify or diagnose participants with shoulder impairment is poor. Further, physical therapists have poor to fair ability to agree between each other or within themselves when viewing scapular positions or movements.

**Diagnostic Accuracy**

Visual evaluation of scapular position and movements is often suggested to be included as part of the physical examination in patients with shoulder dysfunction although it has not commonly been described as a diagnostic test. The findings from the current study suggest that clinician determination of symptomatic shoulder from the visual analysis is not diagnostic of an injured shoulder and should be used neither as a screen (high sensitivity) nor as a confirmatory test (high specificity). At best, physical therapists were likely to see symmetry in people without shoulder impairment approximately 60% of the time as indicated by the calculated specificity. The sensitivity, or probability of determining scapular asymmetry in patients currently being treated for shoulder impairment, was near 35% indicating a high risk of false negative findings. Thus, the majority of the time physical therapists were unable to determine asymmetry in shoulder-impaired patients. Index tests with high sensitivity are thought to be effective at ruling out the presence of the injury when the test in negative, while high

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**Table 2. Demographic Information (Mean ± SD) of Patient Participants**

<table>
<thead>
<tr>
<th></th>
<th>Shoulder Impaired Group (n=6)</th>
<th>Control Group (n=6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>32.7 ± 14.8</td>
<td>34.5 ± 8.7</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>77.6 ± 18.1</td>
<td>71.9 ± 18.8</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>171.4 ± 5.3</td>
<td>166.4 ± 12.2</td>
</tr>
<tr>
<td>SPADI score</td>
<td>22.7 ± 13.2</td>
<td>0.0 ± 0.0</td>
</tr>
</tbody>
</table>

**Table 3. Contingency Table**

<table>
<thead>
<tr>
<th>Physical Therapist Diagnosis as Shoulder Injured</th>
<th>Currently Treated for Shoulder Impairment</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>YES</td>
<td>57</td>
<td>93</td>
</tr>
<tr>
<td>NO</td>
<td>107</td>
<td>139</td>
</tr>
<tr>
<td>Totals</td>
<td>164</td>
<td>232</td>
</tr>
</tbody>
</table>

**Table 4. Reliability Data**

<table>
<thead>
<tr>
<th></th>
<th>Interrater (κ)</th>
<th>Intrarater (α)</th>
<th>Intrarater Agreement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static Symmetry</td>
<td>25.5</td>
<td>51.4</td>
<td>69</td>
</tr>
<tr>
<td>Dynamic Symmetry</td>
<td>18.1</td>
<td>50.8</td>
<td>68</td>
</tr>
<tr>
<td>Determination of Injured Shoulder</td>
<td>15.5</td>
<td>35.3</td>
<td>59</td>
</tr>
</tbody>
</table>
of psychometric properties associated with clinical diagnostic testing. The outcomes of this study and those quantifying diagnostic accuracy of the painful arc test highlight the range of accuracy of shoulder tests generally. Thus, there is a need for additional clinical examination techniques or clusters of examination findings that exhibit greater psychometric properties in diagnosing shoulder injuries.

**Reliability**

Prior studies have assessed agreement between clinicians in determining scapular symmetry. The range of interrater agreement from prior studies was widely variable (Table 5) which is likely due to study differences in the injury types included, plane of elevation, loaded or unloaded conditions, clinician experience, and/or visualization method employed (in vivo or video). The agreement between therapists for this study was also variable and ranged from $\kappa = 15.5 - 25.5$ for the various measures analyzed.

One of the unique aspects of this study was the inclusion of a group of physical therapists performing the same assessment on two separate occasions, which allowed calculation of intrarater reliability (day to day or test-retest agreement). Intrarater reliability simulates clinical practice as clinicians evaluate and re-evaluate the same patient characteristics over multiple sessions during the course of treatment. Physical therapists agreed with themselves nearly 70% of the time. However, after taking chance agreement into account the agreement values for static and dynamic agreement yielded $\alpha = 51.4$ and 50.8 respectively. Further, the agreement on the injured shoulder yielded $\alpha = 35\%$ which does not take into account if this was a correct decision or not. Thus, after accounting for chance agreement, nearly 35% of the time a clinician will report the same injured

<table>
<thead>
<tr>
<th>Author/Year</th>
<th>Range of Interrater Agreement (kappa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kibler, 2002</td>
<td>31 - 42</td>
</tr>
<tr>
<td>Hickey, 2007</td>
<td>17 - 34</td>
</tr>
<tr>
<td>Uhl, 2009</td>
<td>40 - 44</td>
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<tr>
<td>McClure, 2009</td>
<td>48 - 61</td>
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<tr>
<td>Struyf, 2009</td>
<td>36 - 78</td>
</tr>
<tr>
<td>Bailie, 2012</td>
<td>8 - 26</td>
</tr>
</tbody>
</table>

To date only one study has quantified the sensitivity and specificity of visual dyskinesis assessment. Uhl and colleagues used *in vivo* visual analysis in the sagittal and scapular planes on 56 participants, of which, 32 were symptomatic and reported higher sensitivity and lower specificity values (scapular plane: sens: 74%, spec: 31% and flexion: sens: 78%, spec: 38%) than found in the current study. There are two main differences between these studies. First, the prior study used *in vivo* observation of shoulder movements in two planes of elevation compared to the static picture and video method used in this study. Second, the prior investigation used two highly experienced clinicians with specialization in shoulder dysfunction; whereas the current study used a group of 33 clinicians with varying levels of orthopaedic experience. It is possible that either of these factors or the combination of them led to the disagreement between findings.

The diagnostic accuracy found in the current study should be placed in context with the accuracy of other shoulder diagnostic tests. No attempt was made to provide clinical diagnoses for the patients in the current study other than treatment for unilateral pain/dysfunction at the shoulder. Thus, a range of shoulder pathologies was likely included in the current sample. Similarly, impingement may be considered a broad diagnostic category for patients with varying shoulder conditions which has been reported to be assessed using the painful arc test. The painful arc test for shoulder impingement is similar in execution to the visual evaluation used in this study and requires the patient to perform active abduction with a positive test indicated by pain in mid-range (60-120°) of elevation. Prior studies have indicated that the sensitivity of the painful arc ranges from 30-98% with a specificity range of range 4-81%. The findings from the current study fall within each of these wide ranges indicating the large variability

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**Table 5. Reported Agreement of Scapular Symmetry in Previous Studies**

<table>
<thead>
<tr>
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<tr>
<td>Bailie, 2012</td>
<td>8 - 26</td>
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</tbody>
</table>
shoulder on two separate days when viewing the same humeral elevation movement patterns.

The intrarater reliability (κ = 35-51) was higher than between therapists (κ = 15.5-25.5). This finding may be intuitive as individual therapists agreed with themselves at a statistically higher proportion than they agree with others. Yet, the fact that both intrarater and interrater reliability are poor, combined with the low diagnostic accuracy of this test, casts doubt on the use of visual assessment of scapular symmetry as a highly valuable clinical finding. The relative disagreement between physical therapists may have occurred because of the lack of operational definitions provided for scapular symmetry. That is, some clinicians may view subtle differences as normal and rate that patient as exhibiting symmetrical movements whereas others may define the same movement pattern as asymmetrical. Yet when the clinicians rate the same patient twice they are using their own self-defined interpretations of symmetry or lack thereof. Further, the survey questions allowed physical therapists to rate the movement as deviant from symmetry or not and if the shoulder was symptomatic or not. Therefore not all movement deviations were necessarily reported as symptomatic. Prior authors have performed reliability and validity analyses of scapular movement patterns in patients deemed to have obvious dyskinesis defined as a striking, clearly apparent abnormality, evident on the majority of files (dysrhythmias or winging of 2.54 cm [1 inch] or greater displacement of scapula from thorax). Utilizing this method of identification yielded greater reliability (κ range 48-61) than found in the current study and should be considered for clinical determination of scapular dyskinesis.

To date, only one study has completed a day-to-day reliability analysis of scapular movements. The evaluations were completed by one physician and one physical therapist, using methods similar to those utilized in the current study. The previous findings yielded slightly higher day-to-day agreement levels (κ = 49 - 59) compared to those found in the current study (κ = 35 - 51). The findings from the current study are likely more representative of a typical orthopedic physical therapist given the sample size difference between these two investigations (30 vs 2). The agreement values found in this study for both day to day and between therapists are with ranges found in prior investigations, all of which indicate fair to moderate reliability at best. Several factors may make the reliability visual evaluation of scapular movements questionable; these include difficulty determining scapular landmarks, especially in the presence of larger patients, large individual adaptations in scapular movement patterns, use of video versus in vivo visualization.

Previous investigations have compared day to day agreement in determining gait abnormality, using video recordings, in patients with lower extremity orthopaedic impairments. Brunnekreef and colleagues found moderate agreement (ICC range 0.52-0.74) among groups of raters with varying experience. They noted that experience level of the clinicians was associated with higher levels of day to day agreement with “expert” clinicians demonstrating the highest values. The current study did not attempt to differentiate between experience levels of clinicians. Reliability of scapular assessment based on clinical experience is an area which may require further inquiry as more experienced clinicians may exhibit greater reliability within themselves and between each other.

Limitations
Some limitations to this study should be recognized. First, this study used video assessment of unloaded scapulohumeral elevation in the scapular plane. Visualization in vivo with multiple planes of elevation, load conditions, or angles of visualization may yield different results and better approximate clinical examination. Additionally, the inclusion of non-specific shoulder impairment may be viewed as a limitation. Inclusion of patients with one type of shoulder impairment may have led to different results. However, scapular dyskinesis is found across many shoulder pathologies and no evidence links any one particular injury type with specific kinematic adaptation. The relationships between shoulder impairment and scapular dyskinesis is debated as not all shoulder patients will exhibit dyskinesis and many uninjured people exhibit altered scapular movement patterns. Furthermore, operational definitions were not provided for physical therapists. This was done to best replicate clinical examination where
measures of movement variation are self-selected. This may have negatively affected the diagnostic accuracy and reliability scores calculated in this study. The addition of three dimensional scapular movement assessments of participants would have quantified any movement abnormality present and enhanced the findings of this study. Yet, such motion analysis devices are uncommon in the clinic and no relationship between pain and scapular dyskinesis has been reported previously. Finally, only 12 participants with and without shoulder injury were included as patient participants in the study. This small sample size may have limited the findings of this study.

CONCLUSIONS

Scapulohumeral movement evaluation, performed using visual observation, yielded poor to fair reliability and diagnostic accuracy. Physical therapists who utilize movement evaluation to aid in diagnosis of shoulder impairment are cautioned against relying too heavily on such procedures. In the absence of clinical history, the most accurate finding was normal symmetrical movement in patients not being treated for shoulder impairment. Clinically, visual scapular evaluation may have limited utility to diagnosis shoulder impairment but may provide useful in guiding interventions for patients with shoulder impairment that exhibit obvious scapular contribution to shoulder impairment.17,18

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20. McClure P, Michener L. Measures of adult shoulder function: The American Shoulder and Elbow Surgeons Standardized Shoulder Form Patient Self-Report Section (ASES), Disabilities of the Arm, Shoulder, and Hand (DASH), Shoulder Disability...


ABSTRACT

**Background:** Information on baseball injury prevention and pitch count recommendations is growing, however, the incidence of throwing injuries continues to rise. This study is the first to assess knowledge of safe throwing guidelines and risk factors from the perspective of youth athletes.

**Purpose:** The purpose of this study is two-fold: (1) to evaluate knowledge of safe throwing guidelines and (2) to assess the reporting of risk factors for throwing injuries in a sample of youth baseball players.

**Study Design:** Survey study of 98 overhead athletes between the ages of 4 and 18.

**Methods:** A 35-question survey was developed with questions related to knowledge of injury prevention, presence of risk factors associated with throwing injuries, and understanding and compliance with USA Baseball Medical & Safety Advisory Committee (USA BMSAC) overhead throwing guidelines.

**Results:** Respondents demonstrated variability in their knowledge of the USA BMSAC guidelines related to throwing frequencies. The 13-16 year old age group displayed the least knowledge of USA BMSAC guidelines. The 9-10 and 11-12 year old age groups demonstrated the greatest knowledge of recommended BMSAC guidelines. Eighty-five (82/98) percent of the respondents reported that they had never heard of the USA BMSAC guidelines. Sixty-two percent (59/98) disagreed with the statement, “The more you throw, the more likely you are to get an injury”. Fifty-seven percent of respondents (39/98) indicated that they would not seek medical help if they experienced a tired or sore arm during a game.

**Conclusion:** The results of this study suggest that young baseball players demonstrate the need for education on the following topics: the USA Baseball Medical and Safety Advisory Committee throwing guidelines, risk factors for developing throwing-related injuries, the long-term implications of playing with an injured or fatigued arm, and the benefit of seeking medical help when fatigue or soreness is experienced in the throwing arm.

**Level of Evidence:** Level 3

**Keywords:** Baseball, throwing injuries, knowledge
INTRODUCTION

Despite increased media coverage on injury prevention and the advent of safety guidelines and pitch count recommendations, the number of youth baseball players plagued by throwing injuries continues to rise.\(^1\)\(^2\) According to stopsportsinjuries.org, over the past 15 years, there has been “...a fivefold increase in the number of serious elbow and shoulder injuries...” in youth baseball players.\(^3\) Furthermore, “Twenty percent of children ages 8 to 12 and 45 percent of those ages 13 to 14 will have arm pain during a single youth baseball season.”\(^3\) The etiology of throwing related injuries is multi-factorial.\(^2\)\(^4\)\(^5\)\(^6\) Examples may include: playing multiple positions, pitching with arm fatigue and/or soreness, playing on multiple teams simultaneously, and poor throwing biomechanics.\(^2\)\(^5\)\(^6\) In addition, participation on multiple baseball teams, showcases, and year-round play have become increasingly popular with several authors reporting an association between the increased frequency of play and pitching with increased injury rates.\(^2\)\(^5\)\(^6\)\(^7\) Further, there has been speculation that throwing related injuries that manifest in high school or college are a result of microtrauma accumulated from throwing excessively during childhood.\(^6\)

As an effort to increase awareness of and adherence to pitch count recommendations, youth baseball organizations have adopted policies to govern safe pitching practices. Recently, an internet-based survey was administered to a sample of youth baseball coaches. This survey evaluated knowledge of pitch count recommendations set forth by the 2006 USA Baseball Medical and Safety Advisory Committee (USA BMSAC). As a whole, coaches answered 43% of the survey questions correctly. Specifically, coaches from the 11-12 age group displayed the least understanding of the USA BMSAC guidelines answering only 35% of the survey’s questions correctly. Coaches from the 9-10 age group displayed the greatest understanding of the guidelines with an average score of 62% of the survey's content answered appropriately.\(^1\)

Although these results are not necessarily applicable to all youth baseball coaches, they serve to raise awareness about the knowledge gap that exists regarding a consensus guideline for safe pitching practices.\(^1\) Because athletes’ knowledge of their sport typically stems from what is taught by their coaches, perhaps this same knowledge deficit is present among youth baseball players. Youth baseball players must be equipped with adequate knowledge on risk factors and safety guidelines so that they can advocate for themselves. Knowledge in these areas would enhance the players' abilities to recognize early signs and symptoms of overuse injuries and to confidently report these to coaches and parents. Additionally, this knowledge can empower players to actively participate in tracking pitch counts and innings/games played, and this, in turn, could foster greater adherence among parents and coaches.

Resources outlining safe pitching guidelines and other injury prevention measures are available; however, the extensiveness of their dissemination and the degree of understanding and adherence to them is questionable. Survey research can aid in identifying areas of strength and deficit in knowledge and in ensuring that information on injury prevention is being relayed to young overhead throwers. The purpose of this study is two-fold: (1) to evaluate knowledge of safe throwing guidelines and (2) to assess the reporting of risk factors for throwing injuries in a sample of youth baseball players. To the authors’ knowledge, this is the first study looking at the understanding of safe throwing-related guidelines from the perspectives of youth athletes.

METHODS

Survey Development and Description

The authors created a survey with multiple choice and free response questions that were related to demographics and player knowledge of and compliance with the USA BMSAC pitching guidelines.\(^8\) Additionally, the authors included questions to assess attitudes about preventive measures as well as prevalence of other pertinent risk factors. All questions were related to the players' experience during the past year. This survey was modified from an original survey administered to youth baseball coaches, published in Sports Health 2012.\(^1\) A full copy of the survey is included in Appendix 1.

Sampling Overview

Two hundred and eighty-eight paper copies of the survey were distributed to youth baseball players of
all positions between the ages of 4 and 18. Surveys were distributed through contacts at a local baseball training academy and at local youth baseball organizations, however, the conditions in which the surveys were administered were not controlled. Players were instructed to complete the survey anonymously. Because all data were collected in a de-identified manner, informed consent and approval from an institutional review board were not needed.

**Data Entry and Analysis**

All respondents were included in the data analysis. Prior to data entry, answers to multiple-choice questions were assigned numbers (i.e. A= 1, B= 2) for ease of statistical analysis. Categories with assigned numbers were also designed for answers to free response questions for ease of statistical analysis. When inputting data, survey questions left blank or marked with ambiguous answers were categorized as unanswered. For free response answers that included a range (i.e. 5-10), the average of the two numbers was used. If the average included a decimal, it was rounded to the next consecutive whole number for the purpose of designating a category. Once answers were converted into categories, they were further classified into whether or not they were deemed a risk factor for developing a throwing-related injury. Answers were deemed a “risk factor” based on findings in related literature.1,2

All data analyses were performed with SPSS version 21.0 (Chicago, IL). Data was reviewed as a whole and by age groupings. Surveys were originally distributed to athletes between the ages of 4-18 years old, however, only completed surveys from athletes between the ages of 4-16 years were received. Age groupings were based on the age categories designated by Little League Baseball (9-10 years old, 11-12 years old, 13-16 years old).3 A group of eight years old and under was created to account for the respondents that were between the ages of 4 and 8 years old. It is likely that athletes in this particular age group received assistance from an adult if they had difficulty reading or comprehending the material. Categorical data were analyzed through frequencies and percentages and continuous data were analyzed through mean, median, and mode. Cross tabulations were used to consider associations between categorical variables.

**RESULTS**

**General Information and Demographics**

Ninety-eight surveys were returned (34%) and included in data analysis. Each of the final age groups was well represented in this sample (Table 1). Ages of the respondents ranged from 4 years old to 16 years old. There were a variety of playing positions represented in this sample (Figure 1). It is interesting to note that playing four positions was most prevalent in the younger age groups (8 years and under and 9-10 year olds), however, the 9-10 year old age group was also most likely to report playing a single position. Forty-four respondents (50%) reported that they played baseball for nine months or less during the past year. This was most frequently reported among the 8 years and under group (88.2%) and was least frequently reported among the 9-10 year old group (16.7%). The survey revealed that on average, respondents played on more than one team over the course of the past year (2.3) and 53 (55.8%) reported that they did not play another sport in the past year. Only 13 respondents (14%) reported that

<table>
<thead>
<tr>
<th>Table 1. Distribution of ages of respondents in years</th>
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<tbody>
<tr>
<td>Frequency</td>
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<tr>
<td>-----------</td>
</tr>
<tr>
<td>Less than or equal to 8 years old</td>
</tr>
<tr>
<td>9-10 years old</td>
</tr>
<tr>
<td>11-12 years old</td>
</tr>
<tr>
<td>13-16 years old</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>Missing System</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>
they had to miss time playing baseball during the past year because of an injury. Among this group, the most common mode of injury reported (57.1%) was categorized as “non-baseball related”.

**Attitudes and beliefs about risk factors**

Players were asked a series of scenario questions regarding what actions they would take if they got injured during a baseball game. Of these responses, 79 (95.2%) reported that they would tell their coach, 71 (87.7%) reported that they would tell their parent, 53 (73.6%) reported they would see a doctor, physical therapist, nurse, or athletic trainer, and 47 (64.4%) reported that they would continue to play. Similarly, players were asked what actions they would take if they had a tired or sore arm during a baseball game. For these responses, 76 (88.4%) reported that they would tell their coach, 57 (74.0%) reported that they would tell their parent, 44 (61.1%) reported that they would continue to play, and 29 (42.6%) reported that they would see a doctor, physical therapist, nurse, or athletic trainer.

Players were also asked questions regarding their beliefs about injury prevention. Most respondents (68.8%) believed that baseball injuries can be prevented (Figure 2), but less than half (37.9%) agreed with the statement, “The more you throw, the more likely you are to get an injury”. Further, 58 (60.4%) respondents reported that there should be rules on the number of pitches allowed to be thrown and 82 (84.5%) indicated that throwing with correct form was more important than throwing as fast as possible. Respondents who indicated that throwing with speed was more important were all from the 11-12 year old and 13-16 year old age groups.
General knowledge on baseball injuries
Eighty respondents (82.5%) indicated that pitching can put an individual at risk for injury and 61 (64.2%) indicated that playing catcher puts an individual at risk for injury. A total of 57 respondents (60.0%) correctly marked that most baseball injuries are non-contact injuries. Of those who chose “contact injuries” as the answer, 22 (57.9%) were from the 9-10 and 11-12 years old age groups. Seventy-six percent of respondents were unable to correctly identify the elbow as the body part that is most likely to be injured while playing baseball (Figure 3).

Knowledge of the USA Baseball Medical & Safety Advisory Committee pitching guidelines
When asked if they have heard of the USA BMSAC pitching guidelines, 84.5% of respondents replied, “no”, 10.3% replied, “maybe, it sounds familiar”, and 5.2% replied, “yes” (Figure 4). Further, players were asked a series of questions involving these guidelines and were instructed to select the answer that is best for players in their respective age group. The 9-10 year old group displayed the greatest knowledge of these guidelines with an average of 41.6% correctly answered questions. The 13-16 year old group displayed the least knowledge with an average of 25.8% correctly answered questions (Table 2). Data was only reported from the 9-10 year old group and older in order to maintain continuity with the 2012 study assessing coaches’ knowledge of these guidelines.

DISCUSSION
The results of the current survey revealed that knowledge of safe throwing practices was variable among this sample of youth baseball players. This reflects the variability seen in scores among a sample of youth coaches, however, performances within specific age groups differed.1 A variety of factors could influence why this variability exists, but it is important to note that the USA Baseball Medical and Safety Advisory Committee guidelines were released in 2004 and that Little League Baseball did not adopt pitch counts until 2007.5 Since the adoption of these guidelines is relatively recent, their exposure to different age groups may have varied. Furthermore,
that they would tell their coach if they had a tired or sore arm during a game. These conflicting statistics could be attributed to a variety of reasons. Players and coaches surveyed were not from the same geographical region so attitudes and implementation of safety measures may differ. Perhaps players are aware that they should tell their coaches of a tired or sore arm but are not actually doing so. The majority (57.4%) of respondents stated that they would not see a doctor, physical therapist, nurse, or athletic trainer if they had a tired or sore arm during a game. It is crucial to address these findings; Kerut, Kerut, Fleisig, and Andrews stated that the risk for developing injuries requiring surgery increases by 3600% when players frequently pitch with a tired arm.6 In addition, respondents displayed some faulty beliefs about injury prevention that could lead to a lack of adherence to safe practices. The majority (62.1%) disagreed with the statement, “The more you throw, the more likely you are to get an injury”. Further, the ankle was chosen more frequently than the elbow as the body part that was most likely to be injured when playing baseball.

This study has several limitations when interpreting these results. One limitation is several participants did not answer all questions or did not answer the questions correctly, which could be due to the fact that questions and answers and/or instructions may have been difficult for the young players to comprehend. Additionally, free response questions allowed for variable and vague answers. This made it difficult to discern how to categorize certain answers for the reading level of this survey is considered to be a Flesch-Kincaid Grade Level 4.4. Because of this, it is likely that parental assistance was necessary for younger players, particularly the eight years old and under group. Since the conditions in which the surveys were administered were not controlled, it is unknown how much outside assistance was offered to any age group. It is compelling to observe that 84.5% of respondents reported that they had never heard of the USA Baseball Medical and Safety Advisory Committee pitching guidelines but that 73% of coaches in a similar survey1 reported that they adhered to them. This discrepancy could be due to the fact that the respondents from this study play in a different geographical region or that they were not familiar with the official name of the guidelines. Moreover, different guidelines are available and the authors did not determine which one(s) each athlete’s respective organization(s) employed.

Additionally, risk factors for developing throwing related injuries were present in the current sample. When questioned about actions they would take in different scenarios, players indicated behaviors that are potentially hazardous. It is alarming to note that over half of the respondents reported that they would continue playing if they experienced an injury during a game (64.4%) or if they had a tired or sore arm during a game (61.1%). This contrasts with findings from youth coaches; where only 19% reported that they had players pitch with a tired or sore arm.1 The current findings indicated further discontinuity on this topic; 74% of players reported that they would tell their coach if they had a tired or sore arm during a game. These conflicting statistics could be attributed to a variety of reasons. Players and coaches surveyed were not from the same geographical region so attitudes and implementation of safety measures may differ. Perhaps players are aware that they should tell their coaches of a tired or sore arm but are not actually doing so. The majority (57.4%) of respondents stated that they would not see a doctor, physical therapist, nurse, or athletic trainer if they had a tired or sore arm during a game. It is crucial to address these findings; Kerut, Kerut, Fleisig, and Andrews stated that the risk for developing injuries requiring surgery increases by 3600% when players frequently pitch with a tired arm.6 In addition, respondents displayed some faulty beliefs about injury prevention that could lead to a lack of adherence to safe practices. The majority (62.1%) disagreed with the statement, “The more you throw, the more likely you are to get an injury”. Further, the ankle was chosen more frequently than the elbow as the body part that was most likely to be injured when playing baseball.

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| Table 2. Percent of correct answers for ages included in the USA Baseball Medical and Safety Advisory Committee pitching guidelines |
|---------------------------------|----------------|----------------|----------------|
| Question                        | 9-10 years    | 11-12 years    | 13-16 years    |
| How many pitches should be thrown per GAME? | 59.3% | 40.0% | 6.3% |
| How many pitches should be thrown per WEEK? | 26.9% | 46.9% | 33.3% |
| How many pitches should be thrown per SEASON? | 44.0% | 46.9% | 50.0% |
| How many pitches should be thrown per YEAR? | 36.0% | 28.1% | 14.3% |
| TOTAL:                          | 41.6%         | 40.5%         | 26.0%         |
the value of the safety guidelines and the importance of communicating with their coaches. As evidenced by the current findings, there is variability in the distribution of knowledge regarding these measures. Education for all involved with youth baseball is beneficial, however, there should be a particular focus on the youth players. Even if baseball organizations institute strict safety rules and coaches adhere to them, the prevalence of subjective risk factors can remain. Players may choose to not report factors such as arm fatigue or playing on multiple teams because they want to continue to play and may not understand the serious, long-term implications. Further, players may avoid seeking care from a healthcare provider for fear that they may be required to remain idle and will have to miss out on their seasons. Healthcare providers who have the opportunity to interact with this population should intervene and administer applicable educational interventions. While healthcare providers have access to ample amounts information regarding prophylactic care, athletes continue to be plagued with overuse injuries. Perhaps the delivery of educational interventions is the issue. It is possible that healthcare providers have cultivated an environment of fear of injury and this could be why athletes are keeping quiet. Potential barriers could be that athletes and parents do not understand the significance of the information, or are overwhelmed by it, or are not seeking healthcare for fear or being told to refrain from playing. Healthcare providers should consider catering messages of prevention in a way that is personalized for each individual athlete and situation rather than reciting the same general statements for everyone. Healthcare providers typically have the opportunity to learn the personalities and learning styles of the athletes they treat so they should carefully construct educational interventions according to each individual’s specific needs. These interventions can be presented during clinic visits and through community outreach seminars. If greater strides are made by healthcare providers to educate youth baseball players, perhaps the incidence of throwing injuries can be reduced and, essentially, playing careers can be prolonged.

CONCLUSION
The results of this survey research suggest that young baseball players demonstrate the need for
education on the following topics: the USA Baseball Medical and Safety Advisory Committee throwing guidelines, risk factors for developing throwing-related injuries, the long-term implications of playing with an injured or fatigued arm, and the benefit of seeking medical help when fatigue or soreness is experienced in the throwing arm. Enhanced knowledge in these areas may empower young baseball players to take an active role in their own injury prevention.

REFERENCES
APPENDIX 1

Instructions: Please answer the questions below as best as you can. You do not need to write your name on any of these papers.

Please answer these questions about yourself:

1. What is your age? ____________

2. Please put a (X) next to the positions you play:
   [ ] Pitcher
   [ ] Catcher
   [ ] Infielder
   [ ] Outfielder

3. How many months during the past year did you play baseball? ____________

4. How many baseball teams did you play on last year? _________________

5. If you played on more than 1 team during the past year, can you name all the teams and write what type of a team it is?
   For example: 1. Dodgers, AAU travel team
   2. Lightning, Jonesville Little League

   ___________________________________________________________________
   ___________________________________________________________________
   ___________________________________________________________________
   ___________________________________________________________________

6. Do you ever play in showcases?
   a. Yes  b. No

7. If the answer is yes, please write how many in the past year ________________

8. Did you play any other sports during the past year?
   a. Yes  b. No

9. Do your coaches know how many teams you play on?
   a. Yes  b. No

10. Did you ever have to miss any time playing baseball in the past year because you hurt yourself?
    a. Yes  b. No
11. If the answer was yes, how did you hurt yourself?

________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________

12. If you had to miss time playing baseball during the past year because you were hurt, how many days did you miss?_____________________________

13. If you got hurt during a baseball game, what would you do?
   a. Tell your coach?
      i. Yes    ii. No
   b. Tell your parent?
      i. Yes    ii. No
   c. Keep playing?
      i. Yes    ii. No
   d. Go see a doctor, physical therapist, nurse, or athletic trainer?
      i. Yes    ii. No

14. If you had a tired or sore arm during a baseball game, what would you do?
   a. Tell your coach?
      i. Yes    ii. No
   b. Tell your parent?
      i. Yes    ii. No
   c. Keep playing?
      i. Yes    ii. No
   d. Go see a doctor, physical therapist, nurse, or athletic trainer?
      i. Yes    ii. No

15. Please circle whether or not you agree with this statement:
   *Baseball injuries can be prevented*
   a. Agree    b. Disagree

16. Have you heard of the USA Baseball Medical & Safety Advisory Committee pitching guidelines?
   a. Yes       b. No       c. Maybe- it sounds familiar

17. Please circle if you agree or disagree with this statement:
   *The more you throw, the more likely you are to get an injury?*
   a. Agree    b. Disagree

18. Do you think there should be rules on the number of pitches a pitcher your age should be allowed to throw?
   a. Yes       b. No
19. Which of these are more important to you?
   a. Throwing as fast as possible
   b. Throwing with correct form

The next questions are about baseball injuries:
1. Most injuries in baseball are:
   a. Contact injuries (one player hits or crashes into another)
   b. Non-contact injuries (an injury that does not involve another player)

2. What body part are you *most likely* to hurt while playing baseball?
   a. Ankle
   b. Elbow
   c. Knee
   d. Back

3. Can playing catcher put you at risk for hurting yourself?
   a. Yes  b. No

4. Can pitching can put you at risk for hurting yourself?
   a. Yes  b. No

The next questions are about pitching counts. Please pick the answer that you think is best for players that are the same age as you.
1. How many pitches are you supposed to throw per game?
   a. 50
   b. 75
   c. 100
   d. more than 100 is ok

2. How many pitches are you supposed to throw per week?
   a. 75
   b. 100
   c. 125
   d. more than 125 is ok

3. How many pitches are you supposed to throw per season?
   a. 1000
   b. 2000
   c. 3000
   d. 4000

4. How many pitches are you supposed to throw per year?
   a. 1000
   b. 2000
   c. 3000
   d. 4000

5. Do you think other players (or their parents or coaches) count the number of pitches they throw?
   a. Yes  b. No
Please answer the questions below only if you pitch. If you are not sure of an exact number, please write your best guess.

1. Do you or does someone at your games count how many pitches you throw?
   a. Yes  
   b. No

2. If someone keeps track of how many pitches you throw, how often does the person do it?
   a. Every game
   b. Most games
   c. Some games
   d. Never

3. In the past year, what is the total number of months you pitched?_____________

4. In the past year, how many games did you pitch in? ___________________________

5. In the past year, how many pitches did you throw per game?_____________

6. In the past year, how many days did you rest after pitching in a game?_____

7. Please write the types of pitches that you throw and who taught you how to throw them.

___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
ORIGINAL RESEARCH

BASEBALL PLAYERS WITH ULNAR COLLATERAL LIGAMENT TEARS DEMONSTRATE DECREASED ROTATOR CUFF STRENGTH COMPARED TO HEALTHY CONTROLS

J. Craig Garrison, PhD, PT, ATC, SCS¹
Chris Johnston, MS, ATC²
John E. Conway, MD¹

ABSTRACT

Background: Ulnar Collateral Ligament (UCL) tears are common in baseball players. Alterations in rotator cuff strength are believed to be associated with injury to the shoulder and/or elbow in baseball players.

Hypothesis/Purpose: Baseball players diagnosed with a UCL tear will demonstrate decreased internal (IR) and external rotation (ER) force as an indication of isometric muscular strength in the throwing arm compared to IR and ER force of the throwing arm in healthy baseball players. The purpose of this study was to examine isometric IR and ER strength of the shoulder in baseball players with UCL tears at the time of injury compared to healthy baseball players.

Study Design: Case-control study design

Methods: Thirty-three of the participants were diagnosed with a UCL tear and thirty-three were healthy, age- and position-matched controls. All of the participants played baseball at either the high school or collegiate level and volunteered for the study. Isometric rotator cuff strength measurements for internal (IR) and external rotation (ER) were performed with the arm held to the side at 0° of shoulder abduction. All measurements were taken bilaterally and the means of the throwing and non-throwing arms for IR and ER in the UCL group were compared to the means of the throwing and non-throwing arms in the healthy group. One-way ANOVAs were used to calculate differences between groups (p < 0.05).

Results: Baseball players with UCL tears demonstrated significant rotator cuff strength deficits on their throwing arm IR (p < .001) and ER (p < .001) compared to throwing arm IR and ER in the Healthy (UCL IR = 131.3 ± 31.6 N; Healthy IR = 174.9 ± 20.7 N) (UCL ER = 86.4 ± 18.3 N; Healthy ER = 122.3 ± 18.3 N). On the non-throwing arm, the UCL group was weaker in both IR (135.0 ± 31.1 N; p < .001) and ER (93.4 ± 22.8 N; p < .001) than IR (172.1 ± 24.1 N) and ER (122.3 ± 19.1 N) in the Healthy group.

Conclusion: Participants with a UCL tear exhibit lower force values as an indication of isometric rotator cuff strength in both the throwing and non-throwing arms than a healthy cohort.

Level of Evidence: Level 4

Keywords: Overhead athlete, rotator cuff strength, UCL

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INTRODUCTION

Injuries and tears of the ulnar collateral ligament (UCL) are a common occurrence in baseball players; especially pitchers. Currently, there is not one factor that is thought to be the sole contributor to injury of the UCL. Pitching consistently on a year round schedule correlates with an increased risk of injury. Throwing over 100 innings in a calendar year is also correlated with a 3.5 times increased risk of an upper extremity injury. Additionally, pitching related injuries are related to overuse and fatigue, high pitch velocity, and throwing in showcase competitions. As baseball players fatigue and continue throwing, their mechanics may change and therefore may be more susceptible to injury. Strength and muscle function of the shoulder complex is necessary to accommodate the many throws that occur over the long season.

Strength of the internal and external rotators of the glenohumeral joint in baseball players is thought to be an important factor in throwing. During the throwing motion, the internal and external rotators function with high concentric and eccentric muscle contractions in order to propel and decelerate the arm. Increased external rotator cuff muscle activity is seen during the late stages of the cocking phase and may help in stabilizing the humeral head in the glenoid. Several studies have shown that there is an increase in internal rotation (IR) strength and decrease in external rotation (ER) strength in the throwing arm compared to the non-throwing arm in baseball players. Shoulder IR strength that exceeds 100N may place throwing athletes at risk for elbow injury based upon the increasing arm velocity generated by the IR strength and the accompanying distraction forces occurring at the medial elbow during the acceleration and follow-through phases of the throw. Similarly, alterations or imbalances in rotational strength may be correlated to increased injury risk in the shoulder and elbow. Trakis et al demonstrated that a decrease in supraspinatus and middle trapezius strength and an increase in relative internal rotation strength is associated with an increase in pain with throwing at the elbow and shoulder. Likewise, in a study examining preseason upper extremity strength measurements in professional baseball pitchers, increased weakness in ER strength was associated with throwing related injuries that required surgery. As such, it appears that upper extremity rotational strength of baseball players may play a role in injuries of the throwing arm.

While rotational strength has been examined and shown to be related to injuries and pain of the shoulder and elbow in baseball players, to date no study has specifically examined the relationship between altered rotational strength and UCL tears in baseball players. The purpose of this study was to examine isometric IR and ER strength of the shoulder in baseball players with UCL tears at the time of injury compared to healthy baseball players. It was hypothesized that baseball players diagnosed with a UCL tear would demonstrate decreased internal and external rotation strength in the throwing arm compared to internal and external rotation strength of the throwing arm in healthy baseball players.

METHODS

Participants

This was a case-control study of male baseball players. Sixty-six participants (19.3 ± 1.6 y/o) volunteered to be part of this study and all competed at either the high school or collegiate level. Thirty-three participants with a diagnosis of a UCL tear of the throwing arm were compared with thirty-three age-, activity-, and position- matched controls without a UCL tear (Table 1). The control group was recruited from local high school and colleges and all were healthy at the time of the study. The diagnosis of UCL tear was based upon clinical examination by a fellowship-trained, board-certified orthopaedic surgeon (JEC) and magnetic resonance imaging (MRI) results.

| Table 1. Participant Demographic Characteristics for the Overall Study |
|---------------------------------|------------------|-----------------|----------------|
|                                  | UCL Tear (N = 33) | Control (N = 33) | P value       |
| Age                             | 19.1 ± 1.8 years | 19.4 ± 1.4 years | 0.483         |
| Dominant Limb                   |                  |                 |               |
| Right                           | 28               | 29              | 0.720         |
| Left                            | 5                | 4               |               |
| Years of Experience             | 14.1 ± 1.8       | 14.4 ± 1.4      | 0.483         |
| Position                        |                  |                 |               |
| Pitcher                         | 23               | 18              | 0.210         |
| Catcher                         | 3                | 6               |               |
| Infielder                       | 4                | 6               |               |
| Outfielder                      | 3                | 6               |               |

* Denotes statistically significant difference at the p < 0.05 level.
Participants who sustained a UCL tear were recruited during the evaluation by the participating physician (JEC) and physical therapists. For both the UCL and control groups, individuals were considered for study participation if they were a baseball player between the ages of 13 and 25 years of age. The UCL tear group were included in the study if they met the following criteria: (1) the athlete's ability to throw was affected by the injury, (2) the athlete was unable to continue participating in baseball at the same level as before the UCL tear, (3) clinical examination results were positive for a UCL tear, (4) there was confirmation of a UCL tear diagnosis via MRI, and (5) the athlete was attempting to return to his sport at a competitive level. Exclusion criteria were (1) a previous UCL reconstruction that failed, (2) a previous shoulder surgery for labral or rotator cuff involvement, and (3) if the patient did not plan to return to baseball at a competitive level following the injury. If, after a patient was enrolled, it was discovered that he was experiencing one of the previously listed conditions, then he was removed from data collection. The same exclusion criteria were applied to the control participants. Subjects were consented into the study by an investigator in the outpatient sports medicine facility once they were confirmed to meet the inclusion and exclusion criteria. Following informed consent, objective isometric strength measurements were taken on the shoulder during the initial evaluation. For purposes of this study, strength was defined operationally as isometric hand-held dynamometric (HHD) measures of shoulder IR and ER force. The Institutional Review Board of Texas Health Resources approved the research procedures.

Testing
Rotator cuff strength testing was performed at the initial visit to the outpatient sports medicine facility. All normal control participants were measured before their fall season using the same methods as the UCL group. Bilateral internal rotation (IR) and external rotation (ER) isometric rotator cuff force was measured with a hand-held dynamometer (MicroFET 2, Hoggan Scientific, LLC) using "break test" methodology. Measurements were taken by the same physical therapist (JCG) to ensure consistency and the intra-rater reliability was found to be good (ER: ICC2,1 = 0.94, SEM = 1.3; IR: ICC2,1 = 0.93, SEM = 2.1). During testing of isometric rotational strength, the participant sat at the end of a treatment table and faced the testing therapist with the arm positioned at the side (0° of shoulder abduction) and elbow fixed at 90 degrees. Isometric strength was measured using the HHD placed proximal to the dorsal surface of the wrist for ER and volar surface of the wrist for IR. The participant was instructed to sit tall with shoulders retracted and to rotate their arm outward (ER) or inward (IR) with maximum effort for up to five seconds in duration while maintaining the testing arm at the side with the elbow flexed to 90° (Figure 1A and B). A visual analog scale (VAS) scored from 0 to 10, with 10 being the greatest, was used to monitor any reports of pain during the testing. If any of the subjects reported pain levels greater than 2/10 during testing, their measurements were excluded from the results. An average of two trials were taken for both IR and ER and all measurements were taken bilaterally and recorded in newtons. If there was a wide discrepancy in measurement during one of the trials, an additional trial was recorded for consistency.

Data Analysis
A priori statistical power analysis was performed using throwing arm ER strength as the primary outcome and determined that a total of 20 (10 in the control group and 10 in the UCL group) participants would be needed to detect statistically significant differences based upon an 80% power calculation. The strength means of the throwing and non-throwing arms for IR and ER in the UCL group were compared to the strength means of the throwing and non-throwing arms of the normal controls. One-way ANOVAs were used to calculate mean differences between groups for continuous data while a Chi-Square Test was used to determine differences between categorical data (p < 0.05).

RESULTS
There were no significant differences in height (p = 0.75) or weight (p = 0.19) between groups (Table 2). Baseball players with diagnosed UCL tears demonstrated significant rotator cuff strength deficits on their throwing arm IR (p < .001) and ER (p < .001) compared to throwing arm IR and ER in the Healthy (UCL IR = 131.3±31.6 N; Healthy IR = 174.9±20.7
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N) (UCL ER = 86.4 ± 18.3 N; Healthy ER = 122.3 ± 18.3 N). On the non-throwing arm, the UCL group was weaker in both IR (135.0 ± 31.1 N; p < .001) and ER (93.4 ± 22.8 N; p < .001) than IR (172.1 ± 24.1 N) and ER (122.3 ± 19.1 N) in the Healthy group. Table 3 demonstrates the comparison of force measures as an indication of isometric strength, between groups.

**DISCUSSION**

In this study, baseball players diagnosed with a UCL tear demonstrated decreased isometric rotator cuff strength (IR/ER) in the throwing and non-throwing arms when compared to a healthy control group without a UCL tear. While there is limited information on rotator cuff strength in baseball players with UCL tears, previous studies have provided baseline measurements for rotator cuff strength in little league,11 high school,14,16, and professional17 baseball players. In a group of 165 uninjured high school aged (16±1 y/o) baseball pitchers, rotator cuff strength normative profiles were established for internal and external rotation strength using a handheld dynamometer with the humerus positioned at 90° of shoulder abduction.16 Throwing arm external rotation strength was lower than the non-throwing arm while internal rotation strength was higher in the throwing arm. Conversely, adolescent baseball pitchers who were tested at the end of their season demonstrated greater internal and external rotation strength on their throwing arm compared to the non-throwing arm.15 When pain that had previously occurred in their baseball careers (prior to testing) was considered for these pitchers, internal rotation strength was found to be higher than those pitchers who had not experienced pain. These results suggest side-to-side differences in rotator cuff strength and a possible association between shoulder/elbow pain and strength.

**Table 2.** Participant Heights and Weights

<table>
<thead>
<tr>
<th>UCL Tear (N = 33)</th>
<th>Control (N = 33)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>184.2 ± 9.6</td>
<td>185.9 ± 6.4</td>
<td>0.75</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>84.5 ± 11.3</td>
<td>85.2 ± 8.7</td>
<td>0.19</td>
</tr>
</tbody>
</table>

* Denotes statistically significant difference at the p < 0.05 level.

**Table 3.** Isometric IR and ER force values as an indication of muscular strength of the Throwing Arm and Non-Throwing Arm between groups. (measured in newtons)

<table>
<thead>
<tr>
<th>UCL Tear (N = 33)</th>
<th>Healthy (N = 33)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throwing Arm IR</td>
<td>131.3 ± 31.3 N</td>
<td>174.9 ± 20.7 N</td>
</tr>
<tr>
<td>Throwing Arm ER</td>
<td>86.4 ± 18.3 N</td>
<td>122.3 ± 18.3 N</td>
</tr>
<tr>
<td>Non-Throwing Arm IR</td>
<td>135.6 ± 31.1 N</td>
<td>172.1 ± 24.1 N</td>
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<tr>
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</tr>
</tbody>
</table>

* Denotes statistically significant difference at the p < 0.05 level.
Shoulder rotator cuff strength has been studied as a risk factor for shoulder and elbow injuries in baseball players. A total of 294 young baseball players between the ages of 9 and 12 years were tested for internal and external rotation strength using a handheld dynamometer and followed for elbow injuries over multiple baseball seasons. There were no differences in internal and external rotation strength between the throwing and non-throwing arms. One hundred and fourteen of the 294 participants reported elbow pain and sixty of those were diagnosed with either medial epicondylar fragmentation or osteochondritis dissecans of the capitellum via diagnostic ultrasound. Those individuals who experienced elbow pain were classified into the “elbow injury” group and demonstrated significantly greater internal and external rotation strength measurements in both the throwing and non-throwing arms than the normal group. The odds ratios for elbow pain were 4.11 for shoulder external rotation strength exceeding 80 N and 2.04 for shoulder internal rotation strength exceeding 100 N. These strength values were similar to the findings of the current study in an older population of baseball players of internal (131.3±31.6 N) and external (86.4±18.3 N) rotation strength in the UCL group but lower than those in the healthy group (IR - 174.9 ± 20.7 N; ER - 122.3 ± 18.3 N). Whereas the Harada et al study included young baseball players with reported elbow pain, the current study specifically examined high school and college baseball players with confirmed UCL tears via MRI who demonstrated decreased strength values when compared to a healthy cohort.

In addition to decreased strength measurements in throwing arm in the UCL group, a decrease in non-throwing arm rotator cuff strength was found when compared to the healthy group. These results are not quite as clear, but could plausibly be related to a lack of normalization of strength values to body weight across the subjects in both groups. However, these results more likely may indicate a possible change in central neural involvement in those individuals who experience a UCL tear of the throwing arm. Peripheral and central nervous system activation assists with voluntary muscle contraction, and thus, if impairments occur along the pathway, reductions in the ability to generate muscle force may occur. Previous studies have demonstrated deficits in voluntary muscle activation following joint injuries and immobilization in the lower extremity. Additionally, decreased voluntary activation of the infraspinatus has been shown following a fatigue protocol in the shoulder. Although the current study did not look at voluntary activation or its underlying effects on non-throwing shoulder strength, this theory may have potentially played a role in our findings.

The majority of these participants with UCL tears presented to the sports medicine facility with a reported average duration of symptoms of 4.5 weeks. From the time of injury or beginning of duration of symptoms, these participants halted any throwing or baseball related activities, including any strengthening programs. This decrease in activity may have contributed to an overall de-training of the participant in regards to muscle strength which could have potentially contributed to deficits in non-throwing arm rotational strength via cross education.

Limitations
Isometric rotator cuff strength was measured at time of injury with these baseball players diagnosed with a UCL tear. As such, it is not possible to define the lack of strength in the throwing and non-throwing arms as a causative factor that may have contributed to the UCL tear. Prospective research, measuring rotator cuff strength prior to the season with tracking of the development of UCL tears, is needed. Similarly, pain during rotator cuff strength testing in these athletes may have played a role in the deficits seen between groups. Although constraints were implemented within the methods to control for pain contributions to strength testing, and none of the UCL group reported any pain during testing, the authors cannot be absolutely certain that pain did not influence the strength results. Finally, rotator cuff strength in the current study was evaluated isometrically with the participant in a seated position and the testing arm held to the side with the elbow flexed. This position is not representative of the functional throwing motion, however, it does allow for better standardization and reliability between measures than testing the shoulder at 90° of abduction; and at least for this study was sensitive enough to detect rotator cuff strength deficits.

CONCLUSION
Baseball players diagnosed with a UCL tear demonstrate decreased rotator cuff strength on both their...
throwing and non-throwing arms when compared to healthy age- and position-matched controls. These data do not necessarily indicate a causal factor for UCL tear, although these results may help clinicians by providing a framework for assessment and treatment of this population of baseball players. Early recognition of rotator cuff strength deficits in a baseball player with a UCL injury is important, and should be evaluated and managed as part of non-operative care. Knowledge of strength deficits may assist the clinician in exercise prescription for the UCL injured athlete.

REFERENCES


ABSTRACT

**Background:** Functional assessments are conducted in both clinical and athletic settings in an attempt to identify those individuals who exhibit movement patterns that may increase their risk of non-contact injury. In place of highly sophisticated three-dimensional motion analysis, functional testing can be completed through observation.

**Hypothesis/purpose:** To evaluate the validity of movement observation assessments by summarizing the results of articles comparing human observation in real-time or video play-back and three-dimensional motion analysis of lower extremity kinematics during functional screening tests.

**Study Design:** Systematic review

**Methods:** A computerized systematic search was conducted through Medline, SPORTSdiscus, Scopus, Cinhal, and Cochrane health databases between February and April of 2014. Validity studies comparing human observation (real-time or video play-back) to three-dimensional motion analysis of functional tasks were selected. Only studies comprising uninjured, healthy subjects conducting lower extremity functional assessments were appropriate for review. Eligible observers were certified health practitioners or qualified members of sports and athletic training teams that conduct athlete screening. The Quality Assessment of Diagnostic Accuracy Studies 2 (QUADAS-2) was used to appraise the literature. Results are presented in terms of functional tasks.

**Results:** Six studies met the inclusion criteria. Across these studies, two-legged squats, single-leg squats, drop-jumps, and running and cutting manoeuvres were the functional tasks analysed. When compared to three-dimensional motion analysis, observer ratings of lower extremity kinematics, such as knee position in relation to the foot, demonstrated mixed results. Single-leg squats achieved target sensitivity values (>80%) but not specificity values (>50%). Drop-jump task agreement ranged from poor (<50%) to excellent (>80%). Two-legged squats achieved 88% sensitivity and 85% specificity. Mean underestimations as large as 19° (peak knee flexion) were found in the results of those assessing running and side-step cutting manoeuvres. Variables such as the speed of movement, the methods of rating, the profiles of participants and the experience levels of observers may have influenced the outcomes of functional testing.

**Limitations:** The small number of studies used limits generalizability. Furthermore, this review used two dimensional video-playback for the majority of observations. If the movements had been rated in real-time three dimensional video, the results may have been different.

**Conclusions:** Slower, speed controlled movements using dichotomous ratings reach target sensitivity and demonstrate higher overall levels of agreement. As a result, their utilization in functional screening is advocated.

**Level of Evidence:** 1A

**Keywords:** 3D motion analysis; functional screening; lower extremity; observation.
BACKGROUND

Optimal performance and avoidance of injury, both in sports and in everyday life, may depend on the quality of lower extremity movement. While anatomical variance is widely accepted, certain dynamic lower extremity movement patterns have been categorized as potential precursors to non-contact lower limb injury.\(^1,2\) Excessive hip internal rotation has been linked to patellofemoral pain,\(^3,4\) non-contact anterior cruciate ligament trauma\(^5-7\) and iliotibial band syndrome.\(^8\) Therefore, the assessment of functional tasks including squats, single-leg squats and drop-jumps have been used to evaluate an individual's injury risk and to direct the content of training programs.\(^9\)

Multi-camera, three dimensional (3D) motion analysis has been found to have excellent reliability in assessing lower extremity kinematic variables\(^6\) and is recognized as the gold standard in kinematic assessment.\(^10\) Although highly sophisticated, the cost, resource requirement and lengthy data collection times make the use of 3D motion analysis relatively uncommon. Alternatively, clinicians commonly use visual or video observation to rate functional movements and evaluate the quality of lower extremity kinematics.\(^11,12\) During this form of functional assessment, observers recognize that proximal pelvic position impacts knee loading and control\(^13\) while, distally, the foot can be used as a reference marker to define knee position.\(^14\)

Several authors have investigated the levels of agreement within and between observers assessing lower limb kinematics.\(^11,16,17\) Experienced physiotherapists observing four lower extremity functional tasks (two-legged squat, single-leg small knee bend, lunge, and hop lunge) have demonstrated high levels of intra-rater agreement and fair-to-good inter-rater agreement.\(^17\) Similarly, Poulsen and James\(^16\) found that novice clinicians assessing a single-leg squat were able to track Knee Frontal Plane Projection angle (FPPA), a measure of knee alignment used to denote valgus projection. Inter-rater and intra-rater agreement also exists between clinicians evaluating unilateral squats and lateral step-down tasks, however, these levels of agreement were low.\(^11\) The aforementioned results testify to observer reliability. However, only a few studies have investigated the validity of human observation using 3D motion analysis as a reference standard and, to the best of the authors' knowledge, no systematic review of this comparative literature has been conducted.

Therefore, the purpose of this systematic review is to evaluate the validity of movement observation assessments by summarizing the results of articles comparing human observation in real-time or video play-back and three-dimensional motion analysis of lower extremity kinematics during functional screening tests.

METHODS

Data sources and search strategy

A computerized systematic search was conducted through Medline, SPORTSdiscus, Scopus, Cinhal, and Cochrane health databases between February and April of 2014. Key search terms were gait or walk* or "biomechanical analysis" or "functional analysis" or "movement analysis" or "motion analysis" or "kinematic analysis" or "3D motion analysis" or "2D motion analysis" or "video analysis" or observation and "lower extremity" or "lower limb" or leg. Key words from returned studies, if not already included, were incorporated into the search strategy. (Table 1). Furthermore, the reference lists and 'cited by' applications within databases were perused in an attempt to achieve an all-encompassing research yield.

Study selection

Study selection was defined by pre-determined inclusion and exclusion criteria. Eligible studies

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TABLE 1: Search Results

<table>
<thead>
<tr>
<th>Search Terms</th>
<th>Number of Studies</th>
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<td>Gait</td>
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<tr>
<td>Walk</td>
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<td>Biomechanical Analysis</td>
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<td>Functional Analysis</td>
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<td>2D Motion Analysis</td>
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<tr>
<td>Video Analysis</td>
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<td>Lower Limb</td>
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were those comparing human observation of real-time video play-back to 3D motion analysis of functional tasks. It was pre-determined that only lower extremity functional assessment would be appropriate and that the study samples had to comprise uninjured, healthy subjects. Eligible observers were certified health practitioners that incorporate observation in their assessments or qualified members of sports and athletic training teams that conduct athlete screening.

A stratified eligibility assessment was conducted. Initially, study titles were reviewed and titles not matching the inclusion criteria were excluded. Next, the abstracts of selected studies were read, with inappropriate studies being excluded. Finally, full manuscripts of the chosen articles were reviewed. At this stage, studies were excluded if they did not list the health/injury status of the subjects, the vocation of the observers or if it was not categorically stated that human observation and 3D motion analysis were the index test and reference standard respectively. Figure 1 displays the study selection procedure.

**Risk of bias evaluation**
To evaluate the quality of the inclusive research, the Quality Assessment of Diagnostic Accuracy Studies 2 (QUADAS-2) was used. The QUADAS-2 was developed through the School of Social and Community Medicine at the University of Bristol, England. The tool has been used extensively in systematic reviews aimed at the validity of diagnostic tests.\(^{18-20}\) The QUADAS-2 consists of four key domains; patient selection, index test, reference standard, and flow and timing. All four domains utilize a series of signalling questions that assist in determining the risk of bias within the study design. The first three domains also address the study's applicability to the review. In all domains, each signalling question can be answered "yes", "no" or "unclear" and are phrased in such a manner that "yes" indicates a low risk of bias. The creators of the QUADAS-2 indicate that if all questions within a domain are answered "yes", then the risk of bias is low. But if a signalling question is answered "no", then the potential for bias exist.\(^{21}\)

**Data extraction**
The information extracted from the selected papers consisted of participant anthropometrics (sex, age and activity level), characteristics of observers (background, level of experience and amount of training with functional tool protocol), and details of interventions (the number and description of functional screening tools). The heterogeneity of populations, tests and outcomes used precluded a meta-analysis (Table 2). In terms of functional assessment, sensitivity and specificity, respectively, highlight the ability of a task's rating to identify movement char-

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**Table 1. Key search terms**

<table>
<thead>
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<th>Search strategy</th>
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<td>gait OR walk* OR &quot;biomechanical analysis&quot; OR &quot;functional analysis&quot; OR &quot;movement analysis&quot; OR &quot;motion analysis&quot; OR &quot;kinematic analysis&quot; OR &quot;3D motion analysis&quot; OR &quot;2D motion analysis&quot; OR &quot;video analysis&quot; OR observation AND &quot;lower extremity&quot; OR &quot;lower limb&quot; OR leg</td>
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<td>Manuscripts retrieved from reference lists and 'cited by' function in Scopus</td>
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<td>All articles to be included according to inclusion criteria</td>
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**Figure 1. Figure 1 – Search strategy.**
<table>
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<th>Study</th>
<th>Objective</th>
<th>Subjects</th>
<th>Raters</th>
<th>Method/tests</th>
<th>Outcome variables</th>
<th>Results</th>
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<tbody>
<tr>
<td>Ageberg et al - 2010</td>
<td>To validate the observation of a single leg mini squat for assessing the position of the knee in relation to the ankle joint</td>
<td>25 subjects (17 women) aged between 18-37. Recruited from the local community.</td>
<td>2 musculoskeletal physiotherapists with no previous experience of the test scored knee-to-foot position. Before the study both were trained for the test by an experienced examiner. A 3rd examiner, blinded to the observation results, collected the 3D data.</td>
<td>Single-leg mini squat. Participants were recorded using a bar for balance and looking down while bending their knee, without bending forward from the hip, until they could no longer see their toes. This mini squat was repeated 5 times at a defined speed. Opposite leg was held in slight hip flexion and approximately 90° knee flexion. Test outcome variables; knee-over-foot or knee-medial-to-foot. 2-D peak tibial, peak thigh, and peak knee varus-valgus angles (degrees), and 3-D peak hip internal/external rotation, and peak knee varus valgus angles (degrees) were calculated and used for validation of the clinical test. 3D data was collected simultaneously.</td>
<td>Independent t-tests to compare 2D and 3D data. A level of p ≤ 0.05 was chosen to indicate statistical significance. The receiver operating characteristic (ROC) curve to determine the test’s ability to discriminate between those with and without 2D medial knee positioning. An area under the ROC curve close to 0.5 indicates a poor test, and a value close to 1.0 indicates a good test</td>
<td>30 subjects were scored knee-medial-to-foot by observation. These 30 demonstrated higher tibial (p=0.001) and thigh angles (p=0.001) in 2D demonstrating more knee valgus (p=0.001). In 3D, the knee internal rotation angle was also larger (p=0.049) but varus/varus angle was not (p=0.583). Area under the ROC curve was 0.867 denoting a good test (SE 0.082, p≤0.002).</td>
</tr>
<tr>
<td>Eggeren et al - 2009</td>
<td>To determine the reliability and validity of observational risk-assessment tool in evaluating dynamic knee valgus during a drop-jump landing</td>
<td>40 female participants aged between 13-17. Recruited as a convenience sample from local soccer teams.</td>
<td>3 female physiotherapists with a mean clinical experience of 12±3 years. All 3 were mailed a 20 minute training CD prior to testing. No mention of who collected 3D data.</td>
<td>A drop-jump task. Participants were recorded dropping from a 31 cm box onto an embedded force plate then immediately performing a maximum vertical jump. 3 consecutive trials were conducted with a 10 second rest between trials. Throughout, the arms were kept is a 'stop' position. Test outcome variables; high risk (knee medial to 1°) or low risk (knee in line with 1°) toe. 3D data was collected simultaneously.</td>
<td>Physiotherapists’ ratings of each participant's mean knee valgus motion was compared to 3-D motion analysis. The lead author gave each participant an expert rating of high risk or low risk. A ROC curve was constructed, linking the expert ratings with each participant’s mean knee valgus motion value. Desired sensitivity ≥80%; desired specificity ≥50%. A validity cut-off point of 10.87° knee valgus motion was chosen.</td>
<td>3D motion analysis revealed 15 participants to be truly high risk and 25 truly low risk. Sensitivity targets as calculated with the ROC curve were met; by rater 3 at time 1 (87%) and rater 1 at time 2 (87%). All raters exceeded hypothesized specificity targets (time 1=72%,60% &amp; 72%, time 2=64%, 64% &amp; 72%). Although detecting some, examiners missed certain high-risk participants captured by 3D motion analysis.</td>
</tr>
<tr>
<td>Krosshaug et al - 2007</td>
<td>To test the accuracy and precision of researchers in estimating kinematics from video sequences that resemble situations typically leading to ACL injuries.</td>
<td>3 test subjects that were 22, 23 &amp; 25 years old. Gender not stated. Place of recruitment not stated.</td>
<td>6 observers experienced in both ACL injury research and visual video analysis. Professional/vocational background not stated.</td>
<td>The participants performed trials of running and side step cutting maneuvers. 27 composite video recordings, combining different camera views. Knee flexion/extension, knee varus/valgus, knee internal/external rotation, hip flexion/extension, hip adduction/abduction, hip internal/external rotation, approach velocity, vertical velocity, cutting angle, and internal/external rotation of the foot relative to the pelvis were assessed. 35 composite videos were then created from subject 3 for a training session. After the training session, the initial 27 videos were re-assessed. 3D data was collected simultaneously.</td>
<td>Differences between each of the analyst’s estimates and the marker-based measurements as the gold standard for each variable were measured. Paired t-tests were used to examine if the training led to significant improvements in the means (accuracy) for the differences between the estimates and the gold standard. For all analyses, an alpha level of 0.05 was used to denote statistical significance. For the categorical variables (joint motion), a kappa test was used to compare the agreement between the estimates and the gold standard. The strength of agreement was classified as follows: poor (value: &lt;0.20), fair (0.21–0.40), moderate (0.41–0.60), good (0.61–0.80), and very good (0.81–1.00).</td>
<td>Substantial accuracy errors were found at initial testing. Mean error for knee flexion was 19°, indicating a consistent underestimation. Hip angles were also underestimated systematically by an average of 7°. Both hip and knee internal rotations were underestimated by 10° and 12°, respectively. Only small overall changes in the mean error and standard deviations were seen from the pre- to the post-training tests. Overall agreement between estimated and actual direction of the joint motion was poor.</td>
</tr>
<tr>
<td>Onate et al - 2010</td>
<td>To assess the validity of a simple clinical jump-landing movement-assessment tool, the LESS, in identifying subjective 2-dimensional jump-landing motion analysis compared with 3-dimensional high-speed motion-analysis assessment</td>
<td>19 female (mean age 19.5±4) soccer players conveniently sampled from a division 1 institution.</td>
<td>2 certified athletic trainers scored 3 trials. 1 trainer was considered an expert, with 15 years experience, and 1 was novice with less than 1 year of experience. The expert was involved in developing the test instrument and, thus, provided a 1 hour training session for the novice.</td>
<td>Participants were recorded performing a drop-jump task. The drop-jump was performed off a 30 cm box onto an embedded force plate that was 30 cm from the box. On landing with both feet, 2 participants were instructed to jump as high as possible, with the initial landing being used for analysis. 3 trials were performed with a 1 minute rest in between trials. The 1st of both raters trials was used for analysis. 3D data was collected simultaneously. The 18-point landing error scoring system was used to assess the quality of the drop-jump (see appendix 1 for criteria).</td>
<td>Only the expert rater's scores were used to calculate the phi coefficient correlations between the LESS scores and the 3D analysis. An alpha level of P &lt; 0.05 was set a priori for statistical significance. Individual item analysis assessment of percent agreement was calculated and defined as poor (less than 50% agreement), moderate (51–75% agreement), or excellent (80% and above agreement)</td>
<td>For LESS validity, the rater achieved the following percentage agreement and Phi correlation Item scores: 3: 89.5% &amp; Phi: 0.2–21% &amp; Phi: 0.118, 4: 74.7% &amp; Phi: 0.130, 4: 84.6% &amp; Phi: 0.335% &amp; Phi: 0.66% &amp; Phi: 0.87% &amp; Phi: 0.233, 5: 100% &amp; Phi: 0.987% &amp; Phi, 100% &amp; Phi: 0.558% &amp; Phi: 0.188% , 100% &amp; Phi: 0.12% &amp; Phi: 0.12% &amp; Phi: 0.13% &amp; Phi: 0.456.</td>
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</table>
characteristics that are considered high risk, while ensuring those that are low risk are not falsely labelled as high. When provided, sensitivity and specificity values have been reported.

RESULTS
Study selection
The search was conducted in Cinahl, Cochrane, Medline, Scopus and SPORT Discus and returned a total of 1339 studies. At the first selection stage, all titles were reviewed which led to 1313 studies being excluded for not matching the inclusion criteria or as duplicates. Next, all remaining abstracts were read and on the basis of the information provided, 23 additional studies did not meet the inclusion criteria and were excluded. Following manuscript readings, the final three articles were accepted into the review. A further three articles were retrieved as a result of checking the accepted articles reference lists and the ‘cited by’ function in Scopus. (Figure 1).

Methodological quality evaluation results
The risks of bias and applicability concerns of the included studies are presented in Table 3. Several authors have highlighted the representational problems associated with generating an overall quality “score” of clinical trials. Therefore, instead of an overall score, this review has summarized the QUADAS-2 results, including high risk areas.

Risk of bias was unclear for four studies due to a lack of information relating to recruitment strategies, inclusion and exclusion criteria, and subject anthropometrics. The two remaining studies were deemed

Table 2. Study descriptions and results (continued)

| Whatman et al -2013 | To investigate the ability of physiotherapists to visually rate knee and pelvic position in young athletes during lower extremity functional tests, specifically, (1) to investigate intra- and inter-rater reliability, (2) to investigate the validity of ratings and (3) to assess the influence of clinical experience and velocity of movement on rating ability. | The search was conducted in Cinahl, Cochrane, Medline, Scopus and SPORT Discus and returned a total of 1339 studies. At the first selection stage, all titles were reviewed which led to 1313 studies being excluded for not matching the inclusion criteria or as duplicates. Next, all remaining abstracts were read and on the basis of the information provided, 23 additional studies did not meet the inclusion criteria and were excluded. Following manuscript readings, the final three articles were accepted into the review. A further three articles were retrieved as a result of checking the accepted articles reference lists and the ‘cited by’ function in Scopus. (Figure 1). | 23 (11 female) healthy young athletes (11±1 years old). All participants were part of a structured long term athlete development programme and competed in a variety of sports. | Sixty six New Zealand registered physiotherapists agreed to visually rate the video recordings. No test training stated. | Participants were recorded performing 3 lower extremity functional tests (squat, Single-leg squat and Drop jump). All participants were given standardized verbal instructions. The researcher demonstrated each test. Practice for all tests was allowed. 3D data was collected simultaneously. For all tests, physiotherapists responded “yes” or “no” to the question, “Does the patella move medial to the 2nd toe”? Additionally for the Single-leg squat, a “yes” or “no” response was recorded to the question, “Does the pelvis remain neutral in the frontal plane”? All video clips were also rated in the same manner by three musculoskeletal physiotherapists (all PhD or Masters qualified and all senior academics with an average of 15 years clinical experience). 26 of the initially selected physiotherapists repeated visual ratings 3-4 weeks later. | Validity was assessed by comparing the peak 2D and 3D kinematic data between the groups based on the consensus, expert visual ratings (To be used in this instance). | Athletes visually rated as having a patella medial to the 2nd toe alignment were likely to very likely to have increased peak 3D hip internal rotation (SKB=95%, D=95%, SLKB=95%) and adduction (SKB=93%, D=95%, SLKB=95%) in all tests. These athletes were also almost certain to have an increased peak frontal plane projection angle in the Drop Jump (D=98%). Athletes rated as not maintaining a neutral pelvis in the frontal plane were almost certain to have increased lateral pelvic tilt as measured in 3D and 2D (both 100%). |
to be high risk for using convenience samples. Risk of bias regarding index tests and reference standards was unclear for five of the studies, with only one clearly stating that both the index test and reference standard were interpreted without knowledge of the other's results. All studies achieved a low risk rating for flow and timing. One study was considered to be an unclear risk in patient selection as age was the only information provided in relation to participant background, presentation and selection.

All six studies provided clear detail regarding the application of 3D motion analysis, so were considered low risk of reference standard applicability. In terms of the index tests, five of the studies scored specific joint positions (hip and/or knee and/or ankle) in the frontal, transverse and sagittal planes. However, one study used a general scale of one to ten with one representing ‘very poor’ and ten representing ‘very good’ and, as a result was considered a high risk of index test applicability. Another study's index test applicability risk was unclear because instead of a direct comparison, participant observations were validated with expert ratings which, in turn, were validated by 3D motion analysis.

**RESULTS**

**Single leg squat**

Ageberg et al.²⁴ and Whatman et al.⁹ asked observers to rate a single-leg squat by answering ‘yes’ or ‘no’ to whether the knee travelled medial to the 2nd toe during the movement. Observer results were then compared to the findings of 3D motion analysis. The Ageberg et al.²⁴ observers were anteriorly positioned to rate real-time movement and estimated that, of 25 participants, ten had knee-medial-to-foot. When compared to 3D findings, the ten knee-medial-to-foot participants had more hip internal rotation (p = 0.049) than those deemed to have knee-over-foot positioning (10.6° ± 2.1° compared to 4.8° ± 1.8°).

Observers for Whatman et al.⁹ were asked to rate an anterior view recording of a single-leg squat and they achieved the target rating sensitivity value (>80%) but not the target mean specificity value (>50%). These results suggest that those with knee-medial-to-foot alignment were likely to be identified, but that those without medial knee movement had a higher chance of being incorrectly classified.

Weeks et al.²⁵ opted to use a ten point ordinal scale to rate the overall quality of a single-leg squat, with a score of one representing ‘very poor’ and a score of 10 representing ‘very good’. In this instance, observers rated an anterior view recording but were not given rating guidelines for the use of the scale. Instead, they were simply asked to rate the quality of the movement, which resulted in an average score of 6.4 ± 1.3. When compared to the findings of 3D motion analysis, variance in scores was predicted by peak knee flexion (men = 86.2° ± 13.0°, women = 71.5° ± 7.3°), peak knee medio-lateral displacement (men = 44.8° ± 13.9°, women = 52.2° ± 22.7°) and peak hip adduction (men = 15.5° ± 5.0°, women = 20.8° ± 7.1°). Results that suggest the accuracy of observation may depend on the joint or system of joints at which altered movement occurs.

**Drop-jump task**

Whatman et al.⁹ and Ekegren et al.²⁶ compared observer ratings to the results of 3D motion analysis.
of a drop-jump task. Using the same knee-to-foot position rating as previously mentioned, observers in both studies rated anterior view recordings and correctly identified enough participants without knee-medial-to-foot alignment to achieve the target specificity values (≥50% in both). However, the target sensitivity value (≥80%) was only met twice (87% and 87%) for Ekegren et al.26 and, with an overall score of 79%, was missed for Whatman et al.8 These findings suggest that those with knee-medial-to-foot may go unidentified by observers of a drop-jump.

Onate et al.27 used the 13-point LESS to rate a drop-jump. Medio-lateral right side and anterior view recordings were provided for observer rating. Observer agreement with 3D motion analysis was found to be excellent (above 80%) for six of the points, moderate (51%-79%) for four of the points and poor (under 50%) for three points. Of all the points, best agreement (100%) was found when grading ‘toes greater than 30° internal rotation in terms of foot position at initial contact’, and ‘stance width greater than shoulder width’. The three points that resulted in poor agreement were knee flexion at initial contact (21%), initial foot contact (42%) and lateral trunk flexion at initial contact (10%). Taken collectively, these findings suggest that the precision of observation may be dependent on body region under analysis.

Other functional tasks
Whatman et al.9 compared observer assessment to 3D motion analysis findings of a two-legged squat with arms at the side. When asked to determine whether the knee travelled medial-to-foot from anterior view recordings, 88% sensitivity and 85% specificity scores were achieved; both above the author’s target values of ≥80% and ≥50% respectively. While the majority of physiotherapists (1st quartile ≥80% & ≥50%) achieved the target value, those with five years more experience improved rating accuracy (diagnostic odds ratio > 2).

Krosshaug et al.28 found substantial accuracy errors between observer ratings of video play-back and 3D findings of a running and side-step cutting manoeuvre. With one camera at postero-lateral left side, one at the right side (mid-stance) and one anteriorly placed, observers used three different views to rate the movement. Underestimations were seen in the mean error for knee flexion (-19°), hip flexion (at an average of 7°) and knee and hip internal rotation (by 10° and 12° respectively). Multivariate regression analysis showed that knee flexion estimate errors were significantly less when a side camera was present (p=0.02), when the right leg (the one closest to the camera) was analyzed (p=<0.001) and when knee flexion was lower than 30% (p=<0.001). Similarly, hip adduction/abduction estimate error was significantly lower when a front camera was included (p=0.017). In this instance, a significant relationship was observed between the mean estimate error and the true joint angle for 3-D valgus (p=<0.001) and hip flexion (p=<0.001). Overall, these results demonstrate that observation precision is also influenced by range of motion and the plane in which movement is observed.

DISCUSSION
The studies in this review explored levels of agreement between human visual and video observation and 3D motion analysis when assessing a range of functional tasks. Clinically acceptable results, in terms of the accuracy of observer ratings, were achieved when slower, speed-controlled movements such as a single-leg squat24,25,9 and a two-legged squat9 were rated. Conversely, lower levels of agreement were evident when faster, more explosive movements such as a drop-jump26,27,9 or running and cutting manoeuvres28 were assessed. While some tasks may have been easier to rate than others, several additional factors deserve consideration. Varying task instruction, for similar tasks, may have influenced rating accuracy. Furthermore, certain characteristics of the observers used and the chosen samples may have affected final sensitivity and specificity values.

The accurate rating of a functional task will be strongly influenced by how far the movement under scrutiny varies from what is considered normal. Movement that borders on what is considered to be normal may be harder to rate whereas variations, from normal, of a larger magnitude, become more obvious and easier to rate. It may also be fair to assume that, as the difficulty level of a task increases, so too does the likelihood of movement.
beyond normal parameters. Therefore, rating accuracy, in each study may have been affected by how tasks were being performed.

Different methods were apparent for the squat tasks. Ageberg et al.²⁴ encouraged participants to achieve approximately 50 degrees knee flexion, while Whatman et al.⁹ and Weeks et al.²⁵ encouraged participants to squat as far as possible while maintaining control and whole-foot ground contact. Considering that, as knee flexion increases, so does hip flexion, and that increases in hip flexion compromise hip abduction torque as the moment arm of gluteus medius decreases,²⁹ those with more knee flexion may have demonstrated a level of contralateral pelvic drop that was easier to observe.

Upper extremity support used by Ageberg et al.,²⁴ during single-leg squat may have reduced task difficulty and therefore, rating accuracy. As Dingenen, Malfait, Vanreenterghem, Verschueren and Staes³⁰ highlight, knee loading during a single-leg squat is the result of whole body loading. Therefore, engaging the upper extremities may have aided trunk control, reducing the magnitude of aberrant movement and making it harder for observers to detect variance.

Higher drop heights, when drop-jumping, have been found to significantly increase jump height (JH) and relative peak eccentric force (RPEF).³¹ However, Barr and Nolte³¹ failed to notice significant changes between dropping heights of 24 cm (JH = 0.38 ± 0.05; RPEF = 4.15 ± 0.91) and 36 cm (JH = 0.37 ± 0.04; RPEF = 4.36 ± 0.72). Therefore, the different box heights used across the studies, 31 cm,²⁶ 30 cm²⁷ and 25 cm,⁹ is unlikely to have influenced the control of movement and task rating accuracy.

The sensitivity and specificity of any test that requires human rating may be strongly influenced by the skill-level and experience of the person conducting the task. Novice raters using the Functional Movement Screen™ (a battery of seven tests that categorize fundamental movement) have previously demonstrated substantial-to-excellent agreement with expert findings.³⁴ However, when assessing the quality of the movement pattern of a range of lower extremity functional movements, experienced physiotherapists have been found to have a higher level of intra-rater agreement (87% [CI 76-94]) than inexperienced (82% [CI 71-94]) and novice counterparts (80% [CI63-92]).¹⁷ The variance associated with lower levels of agreement, whether intra or inter-rater, may increase the likelihood of poor movement being rated as good and vice versa.

In this review the experience levels of observers ranged from second-year students through to expert raters with 15 years of experience and post-grad qualifications. Interestingly, of the studies that compared novice to expert ratings,⁹,²⁵,²⁷ only Whatman et al.⁹ noticed a significant difference in drop-jump ratings, with experienced physiotherapists achieving a substantial-to-excellent agreement (percentage agreement 82-90%, first order agreement co-efficient 0.65-0.81) compared to the fair-to-substantial agreement achieved by the less experienced group (PA: 76-86%, AC1: 0.56-0.78).

Previous investigators have used expert rating³⁵ and 3D motion analysis³⁶ to demonstrate that individuals with greater hip abduction, knee flexion and knee extension torques are less likely to demonstrate aberrant hip and/or knee biomechanics. Therefore, the baseline activity and strength levels of the participants involved in the studies may have determined the ease with which observers could define lower extremity kinematics and, thus, the overall sensitivity and specificity values. In this review, the three studies rating a drop-jump all recruited active individuals. From this group, both Whatman et al.⁹ and Ekegren et al.²⁶ reported acceptable levels of sensitivity and specificity for the task. Of the three studies rating a single-leg squat, Whatman et al.⁹ (who used an athletic population) and Ageberg et al.²⁴ (who used a mixed cohort of recreationally physically active and not physically active) reported activity levels of their participants. Weeks et al.²⁵ did not provide this detail. As only Whatman et al.⁹ offer single-leg squat sensitivity and specificity values, it remains hypothetical whether or not such values would be similar in the studies using mixed populations.

When selecting a task for functional assessment, consideration should be given to the functional relationship of the task movement and the underlying activity the person partakes in. Running and cutting manoeuvres were, in this review, arguably, the movements that come closest to resembling sporting
activity, however, they were also found to demonstrate the worst rater agreement with 3D data. With significant underestimations seen in a variety of hip and knee movements, it is more likely that, when assessing running-and-cutting, poor movement would be rated as good and that sensitivity values would be unacceptable.

Whatman, Hing and Hume\textsuperscript{39} used 3D motion analysis to explore the relationship between five forms of squatting and jogging. In doing so they found a strong correlation between peak hip, knee and ankle kinematics during the tests and jogging \((r = 0.53-0.93)\) and concluded that squat tests may help physiotherapists determine dynamic lower extremity alignment and risk of injury within jogging cohorts. These findings, suggest that various forms of squatting may offer a strong alternative to sports specific movement when it comes to functional testing.

This review has several limitations that must be considered. The heterogeneity of populations, tasks and outcomes used precluded a quantitative review such as a meta-analysis. Furthermore, the small number of studies identified limits the generalizability of the results. This review focussed on lower extremity kinematics during functional screening. However, in practical terms, this compartmentalised approach may be over-simplistic and lead to misinterpretations of injury risk. Those assessing functional tasks must also understand the influence of and evaluate trunk positioning and whole-body movement. Finally, it is important to recognise that the majority of the studies in this review used 2D video-playback for observation. If the movements had been rated live, in real-time 3D, the results may have been different.

**CONCLUSION**

Lower extremity functional 3D motion analysis is commonly used to identify movement patterns that increase the likelihood on non-contact injuries. However, the process can be expensive, resource-dependant, and time-consuming. A growing body of evidence exists, implying that human observation of functional movement may be a reliable alternative to high technology. Although the reliability of observation has been established, only a few studies have attempted to validate human observation by establishing levels of agreement with the gold standard; 3D motion analysis. From the existing literature, the results of this systematic review demonstrate that the validity of human observation depends on several performance and rating factors. Assessing slower, speed-controlled movements such as a two-legged squat or a single leg squat produced acceptable levels of agreement with 3D. However, agreement was poorer with faster, explosive movements such as drop-jumps, running and cutting manoeuvres. Although, the pelvis, hip, knee and foot positions are often used to classify the quality of functional movement, trunk and overall body positioning impact heavily on lower extremity function and, thus, demand attention. These conclusions need to be considered in light of the risk of bias associated with the included studies. Further high quality studies are needed before a definitive statement on the accuracy of visual assessment of faulty movement patterns of the lower limb can be made.

**REFERENCES**


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ABSTRACT

Background: Landing with the knee in extension places increased loads on ligamentous restraints at the knee versus landing in flexion. Unfortunately, existing methods to predict landing kinematics require sophisticated equipment and expertise. The purpose of this study was to develop predictive models for sagittal plane tibiofemoral landing kinematics from the results of functional tests.

Methods: Twenty-nine female, NCAA-D1 college athletes (mean ± standard deviation, age = 19.03 ± 1.09; mass = 66.56 ± 13.47 kg; height = 171.16 ± 7.92 cm) participated in a descriptive, laboratory study. Participants performed five unilateral, dominant lower extremity (LE) landings from a 35cm platform onto a forceplate. LE three-dimensional kinematics were captured with electromagnetic sensors interfaced with motion analysis software. Then in a randomized order, participants performed three standardized functional tests: single limb triple hop (SLTH), countermovement vertical jump (CMVJ) and the Margaria-Kalamen (MK) test. Sagittal plane tibiofemoral joint angle at initial contact (IC) and excursion (EXC) in the first 0.1s after ground contact were entered into a statistical software package. Multiple linear regression analyses generated one model predicting IC and one predicting EXC from the independent variables. Alpha levels were set a priori at \( p \leq .05 \).

Results: A two variable (MK, SLTH) linear regression model that predicted EXC was significant (Adjusted \( R^2 = .213, p = .017 \)), however the model that predicted IC was not (\( p = .890 \)).

Conclusion: Knee flexion excursion following a single leg landing task may be predicted with the MK and SLTH. The use of functional tests provides a practical means to predict landing kinematics to clinicians working with an active, athletic population.

Level of Evidence: 3, cohort study

Keywords: Anterior cruciate ligament, kinesiology, Margaria-Kalamen, triple hop, vertical jump

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INTRODUCTION

Anterior cruciate ligament (ACL) injuries remain common amongst female athletes. Despite efforts from medical professionals,1–3 ACL injury frequency continues to increase in female intercollegiate athletes.4 Once torn, ACL reconstruction with a six5 to more than 12 month6 rehabilitation is the standard protocol in an attempt to restore preoperative function.

Even with a reconstruction, repercussions from ACL injuries are substantial. Individuals who have undergone an ACL reconstruction have 17%7,8–23%9 increased likelihood of re-injury and of developing knee osteoarthritis.7 In fact, history of previous knee injury in females increases the adjusted odds ratio of knee osteoarthritis to 3.17 versus females without a previous knee injury.10 Additionally, the athlete often faces psychosociological challenges during their time away from participation.11,12 Considering the deleterious long term effects, prevention rather than management of ACL injuries should be the preferred strategy.

While numerous ACL injury risk factors have been identified, laboratory research has consistently noted females exhibit suboptimal lower extremity (LE) landing kinematics when compared to males. Females make ground contact closer to tibiofemoral joint extension13–16 followed by less sagittal plane flexion immediate after contact1,17,18 than males. ACL bundles achieve their greatest length and should therefore be under greatest load as the knee approaches full extension.19 Indeed, research has shown that an extended tibiofemoral joint at and immediate after landing was the most common mechanism for injury in an athletic sample.1 Additional load placed on the ACL with the knee closer to full extension then is more likely to have a deleterious effect on the tissue.

Until recently, sophisticated instrumentation was required to detect faulty landing kinematics. A few years ago, Padua and colleagues developed the Landing Error Scoring System20 and Landing Error Scoring System - Real Time21 as a means by which experienced clinicians could examine landing kinematics in athletes. Though clearly more practical compared to three-dimensional motion analysis, it remains challenging to implement this type of system in clinical settings due to the professional training and expertise that is required to administer. Hence, even a more practical method of predicting LE landing kinematics would be of value to those with limited clinical experience and/or landing assessment expertise.

Previously published work suggests an individual’s ability to rapidly produce LE muscular force is related to tibiofemoral landing kinematics.22 Garcia et al identified the longer it took a subject to produce peak force, not only was there a greater tendency for the subject to land in more of a valgus position but there was also a greater tendency for the subject to undergo a greater amount of valgus excursion during a single leg landing task.22 The time to peak force measure illuminated the relationship between rapid generation of muscle force on landing kinematics at the knee. Theoretically, rapid force generation of the local musculature promotes active stiffness thereby enhancing joint stability and limiting excursion. Furthermore, the ability to quickly produce force provides not only a means by which joint stability may be improved but also a means by which force can be controlled and dissipated via the muscular system thereby limiting stress on the passive restraints. Given the preliminary work by Garcia and colleagues, it is plausible landing kinematics may be predicted from the results of tests in which force is rapidly produced. If the use of easy to administer clinical functional tests are capable of predicting lower extremity kinematics, this approach could provide a low cost and practical model to identify female athletes who are at increased risk of non-contact ACL injury during landing.

Therefore the purpose of this study was to develop regression equations that predict sagittal plane tibiofemoral landing kinematics from the results of select functional tests that require rapid force generation. The hypotheses for this investigation was that the regression models would explain a substantial amount of the variance associated with tibiofemoral sagittal plane landing kinematics.

METHODS

Participants

A sample of healthy, National Collegiate Athletic Association Division I intercollegiate female athletes between 18 and 24 (19.03 ± 1.09 years, mass = 66.56 ± 13.47 kg; height = 171.16 ± 7.92 cm), five
left LE dominant, 24 right LE dominant] were recruited for participation. Females were currently active on the basketball, lacrosse, or soccer team roster. Athletes from these sports were targeted to participate as they are at increased risk for non-contact ACL injury.\textsuperscript{23-25} Participants were excluded from the study if within the last six months they had: 1) utilized crutches for any LE injury or 2) missed a regularly scheduled intercollegiate competition due to a LE injury, 3) engaged in a rehabilitation program for a LE injury or 4) could not perform the landing technique due to pain. In addition, participants were excused if they were allergic to tape adhesive or if they utilized an implanted medical device such as an insulin pump, hearing aid or pacemaker. They also were excused from participation if they reported that they may be, or are trying to become pregnant or otherwise should not be exposed to an electromagnetic field.

**Procedures**

All data acquisition took place in the Kristen L. McMaster Memorial Motion Analysis Laboratory at Duquesne University and each participant followed identical procedures. This quasi-experimental study utilized a randomized descriptive laboratory design. An a priori analysis (G*Power, v3.1.3) based on pilot data indicated a sample size of 36 was needed to obtain a power of .80. Upon arrival to the laboratory, inclusion and exclusion criteria were reviewed to ensure eligibility. Those that met the criteria were provided with a Duquesne University Institutional Review Board approved Consent to Participate form which was completed before progressing further. Height and mass of the participant were assessed with a scientific grade medical beam balance scale (Jarden Corporation; Rye, NY). Participant age and intercollegiate sport played were recorded.

The participant was then asked to step off a 35 cm high wooden platform and land on only one limb without an additional secondary hop. This procedure was repeated two additional trials. The foot the participant preferred for landing two out of three trials was defined as the dominant LE. This operational definition of dominance has been previously described\textsuperscript{26} and recently shown to identify the LE at greatest risk for ACL injury.\textsuperscript{27}

**Landing Kinematic and Kinetic Data Collection**

Participants performed a ten minute warm up on a stationary bike at a self-selected pace. Next, three electromagnetic sensors (Ascension Technology; Milton, VT) coupled with The MotionMonitor software (Innovative Sports Training; Chicago, IL) were utilized to measure three dimensional LE kinematics. Prior work has established the reliability of the motion analysis system.\textsuperscript{28-30} Published research has also established the position and orientation accuracy of the motion analysis system in the specific laboratory environment.\textsuperscript{31} Metal mapping was performed prior to the study to minimize the effect of metal in the testing environment.\textsuperscript{32}

A force plate (Bertec Corporation; Columbus, OH) identified ground contact. Ground contact was operationally defined as when a force greater than or equal to 20N was recorded by the forceplate above a quiet baseline. The forceplate was countersunk into the floor so as to be flush with the testing surface. The motion analysis system and force plate were synchronized and data collected at 100 and 1000 Hertz respectively. Electromagnetic sensors were placed over the L5-S1 junction, mid-lateral thigh and lateral leg just distal to the fibular head. Each of the three sensors were secured using prefabricated neoprene cuffs [Figure 1] and a 5x5 cm piece of double-sided carpet tape (3M; St. Paul, MN) between the cuff and the participant.

The electromagnetic sensors were activated and the segments digitized using a Grood-Suntay coordinate system with the participant standing in the anatomical position. The participant then stood on the 35 cm high wooden platform. The platform edge was located five cm away from the force plate. The participant stood with toes on the leading edge of the platform and hands on their iliac crests. Participants were asked to perform a single limb drop landing onto the forceplate utilizing only the dominant LE while keeping their hands on their iliac crests as kinematic and kinetic data were recorded. Placement of the participant’s hands on their iliac crests sought to control for upper extremity motion during the landing task. A trial was discarded if the participant’s foot did not land fully on the forceplate, if the landing resulted in a secondary hop, or if the hands were removed from the iliac crests. After five
successful trials, participants were given a five min-
ute recovery. Upon removal of the electromagnetic
sensors, the participants then completed the three
LE functional tests in a random order with a five-
minute recovery period between each test.

**Single Limb Triple Hop (SLTH)**

Participants were asked to place the heel of their dom-
inant LE at the leading edge of a marked line and to
keep their hands on their iliac crests throughout the
trials. As per previously reported protocol,33 no other
restrictions were placed on the upper extremities.

They were then instructed to perform three sequen-
tial, dominant LE only hops [Figure 2] while achieving
the greatest horizontal distance possible. Participants
were encouraged to spend the least amount of time
possible in contact with the ground until landing the
third hop. Four practice trials were performed prior to
measured trials. The first practice trial was performed
at self-perceived 50% effort, the second at 75% effort,
and the third and fourth trial at maximal effort. With
each trial, the individual held the landing from the
third hop for at least 1s.33 The individual then per-
formed three maximal trials with a 15 second recov-
ery between trials. The trial was invalidated if the
hands were removed from the hips during the trial
or if the third landing was not held for 1s. The pro-
cedures and trials as described were consistent with
previously established practice.33 Upon completion of
each test trial, the investigator measured the horizon-
tal distance hopped from the starting line to the heel
of the third landing with a standard tape measure
The mean of the three measured trials was utilized
for data analysis.33–35 The SLTH test is an explosive
test that requires the athlete to rapidly produce and
absorb force similar to what would be required dur-
ing sport. Hamilton et al identified the SLTH was a
predictor of muscular power as measured by an iso-
kinetic device.36 Additionally, the SLTH has been pre-
viously studied to assess function after ACL injury in
collegiate-aged females.34 The test-retest reliability
of the SLTH has been previously established with ICC
values ranging from 0.80-0.97.37,38

**Countermovement Vertical Jump (CMVJ)**

The participant stood, facing perpendicular to a
Vertec™ device (Sports Imports; Columbus, OH) with
the dominant LE nearest the device. A standing reach

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**Figure 1.** 3D motion capture sensor placement for single LE drop landing.

**Figure 2.** Foot placement for performance of the Single Limb Triple Hop (SLTH).
starting mark and bound up the stairway taking the steps three at a time (third, sixth, ninth) (Figure 4). The time was recorded between when participant contacted the third step (first pressure switch) and the ninth step (second pressure switch). The participant completed three trials with a 20 second rest between each trial. The best performance time (t) was used to calculate the participant's power (P = \( \frac{\text{Mass} \times \text{Vertical distance between 9th & 3rd step}}{t} \) x 9.8). The MK test is a true measure of power which can be defined as the rate of performing work. Test-retest reliability of the MK has been established as good (ICC = 0.73).48

Statistical Methods

Kinematic data were exported from The MotionMonitor software into an Excel spreadsheet where the five landing trials for each participant were aligned and signal averaged. Next, sagittal plane tibiofemoral joint angles at initial contact (IC) and excursion (EXC) values were determined for each participant. IC was defined as the sagittal plane tibiofemoral angle when the vertical ground reaction force was equal or greater than 20N. EXC was operationally defined as the maximum sagittal plane tibiofemoral angle at initial contact (IC) and previously reported protocol.46 The CMVJ height was calculated as the difference between the maximal height jumped on the best trial and the standing reach height. As with the SLTH, the CMVJ has also been investigated for assessing return to function after ACL injury.49 Likewise, several authors have calculated power values from results of the CMVJ and previously reported protocol.47 The CMVJ height and square and amount of arm swing that occurred with the CMVJ was determined by the participant. Participants performed three trials with a 15 second recovery between trials with this established and previously reported protocol.39 The CMVJ height was measured and recorded using the Vertec™ device with the participant's arm overhead and both hands on the ground. The participant was instructed to jump and touch the highest possible plastic tab on the Vertec™. To perform an optimum jump, the participant was told to bend at their knees, hips, and ankles, then move their arms forward and upward while jumping (Figure 3). The depth of the tabs or pre-jump was allowed. After the first trial, all the tabs below the highest moved tab were pushed aside, participants performed three trials with a 15 second recovery between trials with this established protocol.39 The CMVJ height was calculated as the difference between the maximal height jumped on the best trial and the standing reach height. As with the SLTH, the CMVJ has also been investigated for assessing return to function after ACL injury.49 Likewise, several authors have calculated power values from results of the CMVJ suggesting it reflects some capacity the ability of an individual to rapidly generate force.41,42 CMVJ test-retest reliability has been established as 'good' with reported ICC values 0.82-0.99.44
assessed. Step-wise linear regression models to predict IC angle and to EXC angle were generated. Both models used the results from the independent variables (functional tests) as the predictors. The coefficient of determination and analysis of variance of regression from each model were examined along with an analysis of residuals and outliers. Alpha levels for all analyses were set a priori at $p \leq .05$.

**RESULTS**

Twenty-nine female NCAA Division I athletes from the sports of basketball ($n=3$), lacrosse ($n=12$), and soccer ($n=14$) participated. Descriptive data from the dependent and independent variables are reported in Table 1. A correlation matrix displaying the correlations amongst and between the independent and dependent variables is presented in Table 2. The step-wise linear regression analysis to predict IC from the three LE functional tests was not significant ($p=.890$) (Table 3).

Results from the step-wise linear regression analysis utilizing the three functional tests to predict EXC were significant ($p=.043$). However, further evaluation of the step-wise regression indicated that inclusion of only MK and SLTH provided the most robust model (Adjusted $R^2=.213; p=.017$) (Table 4). The use of MK and SLTH then, was able to explain twenty-one percent of the variance in the model. The EXC model is expressed with the equation: $EXC = 26.79 - .012(MK) + .038(SLTH)$. The addition of CMVJ was not significant in the regression to predict EXC. The MK test was inversely related to sagittal plane EXC ($r=-.404; p=.026$) indicating that power as measured by the MK test went up, EXC went down. No other significant relationships amongst or between the variables were identified.

**DISCUSSION**

ACL injury risk has been shown to increase with the knee near full extension and or with decreased knee flexion excursion immediately after a single

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**Table 1. Variable value Means, Standard Deviations and Range**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean and Standard Deviation</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC</td>
<td>$10.99 \pm 5.64^\circ$</td>
<td>-.73 to 22.90^\circ</td>
</tr>
<tr>
<td>EXC</td>
<td>$34.66 \pm 5.89^\circ$</td>
<td>22.94^\circ to 46.35^\circ</td>
</tr>
<tr>
<td>CMVJ</td>
<td>$42.79 \pm 5.08$ cm</td>
<td>34.92 cm to 52.71 cm</td>
</tr>
<tr>
<td>SLTH</td>
<td>$536.98 \pm 48.41$ cm</td>
<td>426.33 cm to 614.00 cm</td>
</tr>
<tr>
<td>MK</td>
<td>$1035.92 \pm 202.05$ W</td>
<td>753.85 W to 1698.67 W</td>
</tr>
</tbody>
</table>

IC= Sagittal plane tibiofemoral angle when the vertical ground reaction force was equal or greater than 20N
EXC= Maximum sagittal plane tibiofemoral angle (up to 0.1s after IC) minus the IC angle
CMVJ= Countermovement Vertical Jump test
SLTH= Single Leg Triple Hop test
MK= Margaria-Kalamen test

**Table 2. Correlation Matrix for the Independent and Dependent Variables**

<table>
<thead>
<tr>
<th>Variable</th>
<th>MK</th>
<th>SLTH</th>
<th>CMVJ</th>
<th>IC</th>
<th>EXC</th>
</tr>
</thead>
<tbody>
<tr>
<td>MK</td>
<td>r=1.00</td>
<td>r=.089</td>
<td>r=.081</td>
<td>r=-.404</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P=.966</td>
<td>P=.363</td>
<td>P=.132</td>
<td>P=.309</td>
<td></td>
</tr>
<tr>
<td>SLTH</td>
<td>r=1.00</td>
<td>r=.033</td>
<td>r=.150</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>P=.865</td>
<td>P=.436</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMVJ</td>
<td>r=1.00</td>
<td>r=1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>P=.757</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

IC= Sagittal plane tibiofemoral angle when the vertical ground reaction force was equal or greater than 20N
EXC= Maximum sagittal plane tibiofemoral angle (up to 0.1s after IC) minus the IC angle
CMVJ= Countermovement Vertical Jump test
SLTH= Single Leg Triple Hop test
MK= Margaria-Kalamen test

**Table 3. Regression Table for Stepwise Multiple Linear Regression Analysis for IC**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Error</th>
<th>T</th>
<th>P</th>
<th>Adjusted $R^2$</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.989</td>
<td>0.07</td>
<td>.95</td>
<td>.093</td>
<td>0.89</td>
<td></td>
</tr>
<tr>
<td>SLTH</td>
<td>0.016</td>
<td>0.14</td>
<td>.66</td>
<td>.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MK</td>
<td>0.002</td>
<td>0.081</td>
<td>.41</td>
<td>.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMVJ</td>
<td>-0.026</td>
<td>-0.02</td>
<td>-.11</td>
<td>.91</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

IC= Sagittal plane tibiofemoral angle when the vertical ground reaction force was equal or greater than 20N
CMVJ= Countermovement Vertical Jump test
MK= Margaria-Kalamen test

**Table 4. Regression Table for Stepwise Multiple Linear Regression Analysis for EXC**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Error</th>
<th>T</th>
<th>P</th>
<th>Adjusted $R^2$</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>26.79</td>
<td>2.22</td>
<td>.04</td>
<td>.213</td>
<td>0.017</td>
<td></td>
</tr>
<tr>
<td>MK</td>
<td>-0.012</td>
<td>-0.42</td>
<td>-2.49</td>
<td>.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLTH</td>
<td>0.038</td>
<td>0.313</td>
<td>1.87</td>
<td>.07</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

EXC= Maximum sagittal plane tibiofemoral angle (up to 0.1s after IC) minus the IC angle
CMVJ= Countermovement Vertical Jump test
SLTH= Single Leg Triple Hop test
MK= Margaria-Kalamen test
Predicting Sagittal Plane Excursion

Although this investigation did not identify a significant equation to predict sagittal plane IC angle, two (two- and three predictor variable) significant equations using multiple linear regression were identified to predict sagittal plane EXC. The equation that incorporated three predictor variables while statistically significant explained less of the variance when compared to the two variable equation. One could contend, CMVJ as a predictor variable was a more vertically biased movement when compared to the MK and certainly the SLTH. The CMVJ was also the only selected functional test which did not take into account landing as a component of the test result. The test score (maximal jump height) was achieved before the participant prepared for landing. Further, the majority of athletes that participated in the present study do not routinely employ straight vertical jumps as part of their sport activity. Precisely why with the CMVJ variable removed the strength of the regression equation improved is not well understood and would require in-depth study directly comparing these two tests on multiple levels in distinct populations.

Closer inspection of the two-predictor variable regression equation for EXC however raises additional questions. Specifically, as power for the MK test increased, EXC decreased, but as distance for the SLTH increased, EXC increased. The fact that these two relationships are in opposing directions (though the latter relationship (SLTH:EXC) is not statistically significant \((p = .102)\)) suggests the tests are measuring different constructs. The MK test quan-
when the time spent in contact with the ground is minimized due to the myotatic response. Additionally, given that the current investigation focused on predicting sagittal plane landing kinematics, motion during the chosen functional tests were deliberately sagittal plane biased. The functional tests utilized in this study were also selected due to the ease of administration, the familiarity of these tests in most collegiate environments, and their established reliability. Each selected test also incorporated landing as a component of the test. Furthermore, to enhance the performance on two out of three of the functional tests (MK, SLTH), subjects appeared to minimize the stretch-shortening cycle duration thereby limiting the time available for knee flexion excursion. The limitation in knee flexion excursion may have been a strategy to maximize use of the stretch-shortening cycle and improve performance during the test. This test strategy, which was qualitatively observed, further justifies the use of the abbreviated temporal window used during the landing task when quantifying subjects’ kinematics.

Though subjects’ knee flexion range of motion was not overtly limited nor was the time it took a subject to achieve peak knee flexion during the functional tests directly quantified, results from the MK test provide some objective insight. The mean MK time to completion for the sample was 0.663±.070 s. During that time, the participants made two airborne bounds, two landings where energy was absorbed and two landings where take-off forces were generated. In doing so, the sample performed the MK that included six phases in 0.66s approximating the landing observation time window of 0.1s.

Other investigators have reported power may be indirectly calculated from the results of the CMVJ and SLTH tests. To ensure the current data analysis was thorough, the authors’ reanalyzed the data post-hoc after converting the CMVJ and SLTH values with the formulae identified by Sayers et al and English et al. The step-wise regression model to predict IC with the work and power measures remained statistically insignificant ($R^2= .196; p= .135$). The step-wise regression model to predict EXC utilizing the power and work values changed from being statistically significant to non-significant for both the three predictor variable model ($R^2= .177; p= .174$) and the
two predictor variable model ($R^2 = .171; \ p = .087$). These findings suggest there are some components unique to the MK and SLTH that better describe sagittal plane landing behaviors than described by measures of muscular power alone.

**Limitations**
The current study, like all studies has some limitations that should be acknowledged. Based on the a-priori power analysis, 36 subjects were needed to achieve 80% power. Unfortunately, only 29 subjects chose to participate. Essentially, the limited pool of athletes in the targeted sports at the university were exhausted. Despite this, the authors are confident a Type II error was not committed as it relates to the inability to identify a significant regression equation for IC angle given the $p$ value of 0.890 and effect size of .024 for sagittal plane IC angle.

Additionally, it should be appreciated that while the authors did identify a significant regression equation for sagittal plane excursion following a unilateral landing task, only 21% of the variance was explained by the regression equation. The remaining 79% of the variance associated with EXC is due to other variables not explored in the current study. Previous work has suggested that these variables might include the amount of hip joint excursion at landing, hip muscle involvement, lower extremity joint stiffness, trunk posture, available motion at the ankle joint, and lower extremity muscular strength ratios.

Also, the current results are only generalizable to the studied population and are specific to the employed methodology. Future investigations should examine whether other practical tests are capable of predicting sagittal and or frontal plane landing kinematics. Hopefully, future study will reveal regression equations that explain a greater amount of the variance associated with landing kinematics in this population. Of course, other at risk populations participating at various levels of competition would benefit from the development of similar predictive type of equations.

**CONCLUSION**
The utilization of clinical functional tests explained a small but statistically significant amount of variance in tibiofemoral joint excursion in the sagittal plane following a single leg landing task. It was also noted that as power from the MK test increased, EXC following a single leg land decreased. The functional tests utilized in the current study however were not able to predict tibiofemoral joint angle at IC. Future research is needed to develop a practical and cost effective predictive method that explains a greater amount of the variance associated with these measures and to further explore how power is related to landing kinematics.

**REFERENCES**


ABSTRACT

Background: Adaptations in hip range of motion (ROM) and strength have been shown to influence performance and injury risk in overhead athletes. These adaptations in hip ROM and strength have not been examined longitudinally, and little is known regarding whether these changes are a result of pitching workload.

Hypothesis/Purpose: The authors hypothesized that hip rotation ROM and strength would change over the course of a season, and would be associated with pitching workload (number of pitches over the course of a season). The purpose of this exploratory, pilot study was twofold: 1) to examine changes in hip external rotation (ER) ROM, internal rotation (IR) ROM, isometric hip abduction and hip extension strength in pitchers occurring over the course of a competitive season, and 2) to determine the association between changes in hip ROM, strength, and pitching volume.

Study Design: Cohort (longitudinal) study

Methods: Bilateral hip rotation ROM and hip isometric strength was tested pre- and post-season in fourteen collegiate baseball pitchers. Pearson correlations were calculated to determine the association between changes in hip ROM, strength, and pitching workload.

Results: Trail and lead hip ER, trail and lead hip total rotational ROM, and trail and lead hip abduction strength in all pitchers decreased from preseason to postseason (p < 0.01). However, these changes were not significantly associated with pitching workload (p > 0.05).

Conclusion: This study demonstrates that changes occur in hip ROM and strength in collegiate pitchers over the course of a season. These changes were not associated with pitching workload

Level of Evidence: 3

Keywords: Baseball, hip strength, pitch count, range of motion

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INTRODUCTION
The pitching motion is a complex sequence of movements involving the transfer of energy from the lower extremity to the upper extremity and finally to ball release.1-8 In this dynamic process, the lower extremities act as force generators, while the upper extremities direct and control the generated forces before delivery of the ball.1,2,5-8 This motion occurs repeatedly over the course of a season and may contribute to many unique lower extremity adaptations in the overhead athlete.9,10 However, studies examining changes in hip rotational ROM (internal rotation [IR] and external rotation [ER] ROM) have been cross-sectional and it is not known whether these changes occur over the course of a season due to the constant loading of the lower extremities related to pitching workload.1,9,11,12 These adaptations in hip rotational ROM may be analogous to the rotational changes that are known to occur in the upper extremity due to pitching volume.143-25

Restrictions in hip rotational ROM may interfere with proper pitching mechanics, disrupting the efficient transfer of energy as well as the sequential timing of the pitching motion.1,3,11,26-27 Both lead (leg opposite to throwing arm) and trail (leg on same side of the throwing arm) hips are responsible for generating and transferring energy through the kinetic chain during the pitching motion.1,7,28,29 Biomechanical changes in hip rotational ROM have been shown to influence gleno-humeral joint stress as well as ball velocity.1,3,5,30 Therefore it is logical that if restrictions in hip rotational ROM occur over the course of a season due to increased pitching workload, these changes may directly contribute to upper or lower extremity injury.5

In addition to changes in hip rotation ROM, fatigue of hip musculature due to repeated exposure to loading while pitching may result in the failure of proper throwing mechanics over the course of a competitive season.1,31-34 Specifically, a decrease in hip abduction and extension strength has been correlated with upper extremity injury.1,3,32,33 Weakness in hip abductors and extensors may contribute to excessive lower extremity joint stress, which could lead to a higher risk of hip osteoarthritis and labral tears through a mechanism comparable to what has been documented in the shoulder.1,5,9,28,35,36

Pitching workload (number of pitches over the course of a season) may affect pitchers hip rotational ROM and strength differently based on pitching roles. In a cross-sectional study, Laudner et al1 showed differences in hip internal rotation ROM and abduction strength between pitchers and position players.1 This may be a result of inherent differences between pitching (mound), where the movement downward from the pitching rubber into lead foot contact generates the force, compared to flat ground throwing where force is generated strictly through the utilization of the athletes legs.1 Alternatively, these differences may be a function of pitching or throwing volume.1,37 Conversely, no study has reported on the relationship between pitching workload and the adaptations of hip ROM and strength over the course of a competitive season.

Changes in hip ROM and isometric strength as potential injury risk factors have been examined cross-sectionally, but it is not known if these changes occur over the course of a season and whether these changes are a result of pitching workload. Despite the evidence describing the importance of hip rotation ROM and strength while pitching, there is no descriptive data, detailing the change of hip rotation and strength profiles in Division 1 baseball pitchers due to pitching workload over the course of a season. Establishing descriptive data on hip ROM and strength over the course of a season may help in determining whether there is a need to monitor changes in hip ROM and strength during examination to detect potential irregularities which may lead to injury or decreased performance. The purpose of this exploratory, pilot study was twofold: 1) to identify changes in hip ER ROM, IR ROM, isometric hip abduction and hip extension strength in pitchers occurring over the course of a competitive season, and 2) to determine the association between changes in hip ROM, strength, and pitching volume.

METHODS
Subjects
Fourteen Division 1 collegiate baseball pitchers (age = 19.4 ± 1.4 years, height = 189.0 ± 6.4 cm, weight = 96.1 ± 8.4 kg) consented to participate in this study. Nine subjects were right hand dominant and five were left hand dominant. Descriptive data
(including collegiate playing year, innings pitched, pitching workload, and maximum velocity measured with a radar gun) for all subjects are shown in Table 1.

Operational Definitions
The dominant-side hip was defined as the hip on the same side of the throwing arm and referred to as the “trail hip”. The non-dominant-side hip was defined as the hip contralateral to the throwing arm and referred to as the “lead hip”. Strength was defined as the maximum amount of force produced during a five second isometric muscle contraction.

Procedure
All subjects were tested twice: once prior to the beginning of the season before preseason workouts, and again at the end of post-season (Super regional) play, which totaled 66 games (over five months). The individual pitching workload of each subject (calculated by number of pitches thrown during each game) was documented over the course of the season by the University coaching staff. The variability between number of pitches thrown over the course of the season by the subjects is due to the specific pitching role i.e. starter only, starter-reliever, and relief only pitcher. The Institutional Review Board of The University of Florida approved this study.

Hip joint ROM measurements
Subjects were placed in a prone position on a treatment table with the testing hip (hip being measured) in 0 degrees of extension and abduction and knee in 90 degrees of flexion. (Figure 1) A two-tester method was used. One tester stabilized the pelvis with one hand to minimize excess movement and used the other hand to move the hip passively until the end of hip joint ROM (first resistance) was observed. The second tester placed the bubble inclinometer proximal on the medial malleolus and recorded the amount of external and internal rotation. This method was chosen because it has shown good interclass correlation (ICC = .98), ease of use, and similarity to the extended hip position present when throwing a baseball. Total rotational arc of motion was calculated as the sum of hip IR ROM plus hip ER ROM.

Isometric Strength Testing
All isometric strength testing was performed using the microFET 2 digital handheld dynamometer (Hoggan Health Industries, Salt Lake City, Utah). The microFET 2 has a certificate of calibration and

<table>
<thead>
<tr>
<th>Table 1. Descriptive Statistics for Pitchers. Numbers represent mean ± standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
</tr>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>Height (Cm)</td>
</tr>
<tr>
<td>Weight (Kg)</td>
</tr>
<tr>
<td>Throwing Hand Dominance</td>
</tr>
<tr>
<td>College Playing Year</td>
</tr>
<tr>
<td>Innings Pitched (innings)</td>
</tr>
<tr>
<td>Pitching Workload (pitches)</td>
</tr>
<tr>
<td>Max Velocity (mph)</td>
</tr>
</tbody>
</table>

Cm = centimeters; Kg = kilograms; mph = miles per hour
documented accuracy up to 1% and Krause et al reported interrater reliability for hip abduction (ICC = .86 to .92) and hip extension (ICC = .91 to .93)) and intrarater reliability (hip abduction (ICC = .81) and hip extension (ICC = .88). All measurements were recorded in Newton-meters (Nm) and included one trial for each measurement. Make tests were performed for all strength measures.

Hip abduction strength testing was performed with the subject in a side-lying position, with their testing hip facing up. (Figure 2) The test hip was positioned slightly extended beyond the midline of the pelvis. The non-tested lower extremity was positioned into 30 to 40 degrees of hip flexion and 90 degrees of knee flexion. A second examiner stood behind the subject and stabilized the pelvis by placing their hands along the lumbar spine and anterior iliac spine. The dynamometer force pad was placed proximal the lateral femoral condyle and the subject was asked to push into the force pad as hard as they could for five seconds. The repetition was excluded if the subject could not maintain a proper testing position during their maximal contraction. The process was then repeated on the contralateral side.

Hip extension strength was tested using a two-tester method. The subject was placed prone with their knee flexed to 90 degrees. (Figure 3) One tester stood on the ipsilateral side of the test hip and stabilized the pelvis by gripping the lumbar spine, while the other tester positioned the handheld dynamometer force pad over the posterior aspect of the thigh just proximal to the popliteal fossa. All subjects hip extension ROM was measured to ensure that they were able to extend their hip into the test position and no modification to the test had to be made due to hip flexor tightness. The subject was instructed to push into the pad as hard as they could for five seconds. The process was also repeated on the contralateral side.
Statistical Methods
All statistical analyses were performed with SPSS version 20.0 (Chicago, IL) with an $\alpha = .05$. Descriptive statistics were calculated for selected demographic variables. Dependent t-tests were used to calculate differences in lead and trail hip ROM and strength from pre- to post-season. Pearson correlations were used to evaluate the association between number of pitches over the course of a season and changes in hip ROM and strength.

RESULTS

Changes from pre to post season hip rotational ROM measures
Mean changes in pre to post season hip ROM and strength for all pitchers are shown in Table 2. Pitchers displayed significant changes in trail ($t = 5.365, df = 13, p = .001$, mean change $= -10.3$ deg $\pm 7.2$) and lead ($t = 2.887$, $df = 13, p = .01$, mean change $= -7.9$ deg $\pm 10.2$) hip ER, and trail ($t = 4.110$, $df = 13, p = .001$, mean change $= -8.4$ deg $\pm 7.9$) and lead ($t = 2.718$, $df = 13, p = .02$, mean change $= -9.2$ deg $\pm 11.9$) hip total rotational ROM.

Table 1. Pre- to Post-Season Hip Range of Motion and Strength Changes for Pitchers

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Pre Season Measurement ± SD</th>
<th>Post Season Measurement ± SD</th>
<th>Change ± SD (± SEM)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead Hip ER ROM (degrees)</td>
<td>33.4 ± 9.8</td>
<td>25.6 ± 5.7</td>
<td>-7.9 ± 10.2 (± 2.7)</td>
<td>.01*</td>
</tr>
<tr>
<td>Trail Hip ER ROM (degrees)</td>
<td>37.1 ± 7</td>
<td>26.9 ± 5</td>
<td>-10.3 ± 7.2 (± 1.9)</td>
<td>.001*</td>
</tr>
<tr>
<td>Lead Hip IR ROM (degrees)</td>
<td>17.1 ± 7.2</td>
<td>15.1 ± 4.2</td>
<td>-2 ± 6.2 (± 1.7)</td>
<td>.23</td>
</tr>
<tr>
<td>Trail Hip IR ROM (degrees)</td>
<td>15.1 ± 4.6</td>
<td>14.7 ± 5.1</td>
<td>-1.4 ± 3.9 (± 1.0)</td>
<td>.69</td>
</tr>
<tr>
<td>Lead Total Arc ROM (degrees)</td>
<td>50.6 ± 14.8</td>
<td>41.4 ± 8.1</td>
<td>-8.5 ± 11.9 (± 3.2)</td>
<td>.02*</td>
</tr>
<tr>
<td>Trail Total Arc ROM (degrees)</td>
<td>50.3 ± 10.5</td>
<td>41.7 ± 5</td>
<td>-8.4 ± 7.9 (± 2.1)</td>
<td>.001*</td>
</tr>
<tr>
<td>Lead Hip Abduction Strength (Nm)</td>
<td>107 ±10.6</td>
<td>93 ± 10.7</td>
<td>-14 ± 16.9 (± 4.4)</td>
<td>.007*</td>
</tr>
<tr>
<td>Trail Hip Abduction Strength (Nm)</td>
<td>109 ± 16.4</td>
<td>87.7 ± 10.6</td>
<td>-21.7 ± 18.6 (± 4.9)</td>
<td>.001*</td>
</tr>
<tr>
<td>Lead Hip Extension Strength (Nm)</td>
<td>74.6 ± 10.2</td>
<td>70.1 ± 11.9</td>
<td>-4.5 ± 13.5 (± 3.6)</td>
<td>.24</td>
</tr>
<tr>
<td>Trail Hip Extension Strength (Nm)</td>
<td>77.4 ± 11.5</td>
<td>68.7 ± 11.9</td>
<td>-8.7 ± 18.2 (± 3.4)</td>
<td>.06</td>
</tr>
</tbody>
</table>

* Denotes statistically significant difference
SD=standard deviation; Nm=Newton meter; SEM=standard error of measurement.

Changes from pre to post season hip strength measures
Pitchers displayed significant changes in lead ($t = 3.211$, $df = 13, p = .007$, mean change $= -14 \pm 16.9$Nm) and trail ($t = 4.352$, $df = 13, p = .001$, mean change $= -21.7 \pm 18.6$ Nm) hip abduction strength over the course of the season. There were no significant changes in lead ($t = 2.322$, $df = 13, p = .24$, mean change $= -4.5 \pm 16.9$ Nm) and trail ($t = 3.410$, $df = 13, p = .06$, mean change $= -8.7 \pm 18.2$) hip extension strength over the course of the season.
**Relationship between pitching volume and hip ROM**

The results of the correlations can be seen in Table 3. There were no significant correlations between changes in lead hip ER (r = -.430, P = .142), trail hip ER (r = -.181, P = .555), lead hip IR (r = -.208, P = .494), trail hip IR (r = -.173, P = .571), lead hip total rotational arc of motion (r = -.371, P = .212), and trail hip total rotational arc of motion (r = -.100, P = .745) and pitching workload.

**Relationship between pitching volume and hip strength**

Furthermore, there were no significant correlations between pitching workload and changes in lead abduction strength (r = -.145, P = .637), trail abduction strength (r = -.327, P = .275), lead hip extension strength (r = -.085, P = .781), or trail hip extension strength (r = -.006, P = .983).

**DISCUSSION**

This is the first longitudinal study to describe the changes of lead and trail hip ROM and strength throughout the course of a competitive season. Although, numerous studies have established descriptive profiles of pitchers compared to position players, they have been cross-sectional and have not looked at the changes in these parameters due to pitching volume.

The current results illustrate that throughout the course of the season, pitchers, on average, exhibit a statistically significant decrease in lead and trail hip ER and total arc hip ROM, however these changes may not be clinically observable. Due to the excessive positioning of the trail leg into internal rotation while driving and initiating the pitching motion, adaptations may occur in the trail hip restricting the amount of external rotation throughout the course of the season. Conversely, the decrease in lead hip ER may be a result of landing in excessive lead foot IR during the stride phase. Wilk et al described the ideal position of lead foot contact to be between 5 to 25 degrees internal rotation. Therefore, repetitively landing in lead hip internal rotation may result in a decrease in lead hip ER over the course of the season. Hence, changes in total arc of hip rotational motion seen in this study may have been driven by changes in trail hip ER in this sample of athletes. Trail leg internal rotation is critical for the essential positioning of the lead leg during the pitching motion. This repetitive exposure could occur on average of 200 to 1500 times during the course of the season based on the distinctive role of the pitcher, which may explain these changes in total hip rotational ROM.

The findings also detail a decrease in lead and trail hip abduction strength. These findings are important when considered within the context of previous studies detailing the importance of the lower extremity strength while pitching. During the pitching motion, trail hip abductors stabilize the pelvis during wind-up and initiate the forward

| Table 3. Correlations Between Pitching Volume and Changes in Hip ROM and Strength |
|-------------------------------------------------|------------------|------------------|
| Pitching Volume - Lead Hip ER                    | r = -.430        | p = .142         |
| Pitching Volume - Trail Hip ER                    | r = -.181        | p = .555         |
| Pitching Volume - Lead Hip IR                     | r = -.208        | p = .494         |
| Pitching Volume - Trail Hip IR                    | r = -.173        | p = .571         |
| Pitching Volume - Lead Total Arc of Motion        | r = -.371        | p = .212         |
| Pitching Volume - Trail Total Arc of Motion       | r = -.100        | p = .745         |
| Pitching Volume - Lead Hip Abduction Strength     | r = -.145        | p = .637         |
| Pitching Volume - Trail Hip Abduction Strength    | r = -.327        | p = .275         |
| Pitching Volume - Lead Hip Extension Strength     | r = -.085        | p = .781         |
| Pitching Volume - Trail Hip Extension Strength    | r = -.006        | p = .983         |

ER= external rotators; IR= internal rotators.
movement of the pitcher off the mound during the stride phase. Lead hip abductors are active to maintain single leg stance, while the trunk and upper extremity rotate during the deceleration and follow-through phase. These results demonstrate that over the course of a season the repetitive nature of the pitching motion may cause an overall decrease in lead and trail hip abduction strength, which may lead to improper sequencing of force production from the lower extremity to upper extremity. This sequencing pattern may place an increased burden on the upper extremity to generate force when pitching, leading to diminished velocity and increased risk for upper extremity injury.

The results of the current study indicate that changes in ROM and strength were not related to the number of the pitches thrown over the course of a season. Additionally, pitch count did not relate to hip abduction and extension strength. One potential explanation for this is the study’s definition of pitch count. Pitch count may not be a true indicator of overall pitching volume as pitch count only takes into account in game pitching volume and not pitching volume in practice or before or during games. These findings do not support the hypothesis that ROM and strength changes would be dependent on pitch count, however other factors such as the periodization (decrease in-season weight training) and anthropometric factors may play a role.

These results can be used to generate preliminary description of changes that occur throughout the course of a season that do not appear to be related to pitching workload. Based on the current results, changes do occur in pitcher’s hip ROM and strength, however it cannot be determined whether these changes are protective or harmful. The current findings illustrate that these unfavorable adaptations hip ROM and strength which are described by previous authors are occurring through the course of a season and may lead to previously reported upper and lower extremity pathology and decreased overall sport performance. These findings suggest that hip ROM and strength testing should be routinely conducted and changes must be monitored in order to determine if decreases or increases in motion and strength may contribute to dysfunctional throwing mechanics, which will increase injury risk and diminished athletic performance. Additionally, these changes should be monitored to determine if potential subjects should be placed on specific preventive hip rehabilitation programs.

Future research and limitations
This pilot study has limitations that should be considered when interpreting the data. This sample consisted of 14 Division 1 collegiate baseball players, which may have been too small to accurately detect changes or relationships. Future research should look at tracking these parameters over the course of a season with a larger sample size. Additionally, repeated testing over multiple years may give an accurate assessment of changes that occur throughout a competitive season. The current study focused on lead and trail hip IR and ER ROM, abduction strength, and extension strength while pitching. The authors acknowledge that pitching is a complex and dynamic movement that involves the interaction of many other lower extremities ROM and strength variables to perform the task. Therefore other ROM and strength relationships should be examined over the course of the season to better develop the picture of what changes are occurring over time. Future research should also determine if changes in hip rotational ROM and strength throughout the course of a season are related to increased risk of injury or decreased performance in form of decreased velocity or increased earned run average (ERA). While good intra-rater reliability has been previously documented for the strength and ROM measurement methods that were used, an intra-rater reliability analysis for the current measurements was not conducted. This limitation should be considered when evaluating the change measures in the current study; however the authors aimed to maximize reliability by using the same two examiners, one tester and one stabilizer, at both preseason and post season. Also, the study featured a single repetition of isometric strength testing, using a make test, with a handheld dynamometer. There are inherent weaknesses to this type of testing such as the testers strength relative to strength of the lower extremity, size of muscle group tested, and the use of a single trial, which may have led to measurement error. A make test was chosen since multiple studies report that testers need greater strength to perform a “break test” due to eccentric muscle activation.
CONCLUSIONS

This study offers preliminary ROM and strength profiles for lead and trail hip ER, IR, total arc, hip abduction, and hip extension strength in Division 1 collegiate pitchers over the course of a season. However, the changes described may not be a result of pitching workload. Results of this study will inform clinical evaluations and rehabilitative strategies in this population.

REFERENCES


ABSTRACT

**Purpose/Background:** Strength asymmetries are related to knee injuries and such injuries are frequently observed among runners. The purpose of this study was to examine whether long-distance runners have symmetric performance during knee isokinetic testing at two angular velocities.

**Methods:** Twenty-three healthy and well-trained male long-distance runners performed open-chain isokinetic trials for assessment of concentric quadriceps and hamstrings contractions at velocities of 60°·s⁻¹ and 240°·s⁻¹. Data were compared between the lower limbs at different velocities.

**Results:** Peak torque and total work were similar between the limbs. Asymmetry was observed for knee flexor power at 240°·s⁻¹ (237 ± 45 W and 205 ± 53 W, in the preferred and non-preferred limb, respectively). Asymmetry indexes for flexor power were different between the velocities tested (13.1% and 2.21% for 240°·s⁻¹ and 60°·s⁻¹, respectively).

**Conclusion:** A limb asymmetry was observed among runners for knee flexor power, mainly at higher angular velocities (240°·s⁻¹). In addition, H/Q ratios were observed to be contraction velocity dependent.

**Level of Evidence:** 3

**Keywords:** Concentric isokinetics, dynamometer, flexor to extensor torque ratio, peak torque
INTRODUCTION
Most running injuries occur at or around the knee joint, especially overuse injuries such as patellofemoral pain syndrome, iliotibial band friction syndrome, patellar tendinitis, meniscal injuries, and tibial stress fractures.1 Furthermore, training, anatomic and biomechanical factors correlate with running injuries.2 Although some researchers suggest that training errors are the main risk factors for injury,3,4 overuse running injuries may depend on additional factors.2 Zifchock et al5 studied runners with unilateral overuse injuries and suggested that lower limb asymmetries are an important risk factor.5 Bilateral asymmetry indexes reaching magnitudes of up to 10% in knee isometric and isokinetic torque output can be found among runners.6 Asymmetries in the frontal plane movements influence the weight acceptance phase during running, which may increase knee loading.7,8 Although Zifchock et al5 did not find differences in the asymmetry index between injured and non-injured runners,5 a limb that is exposed to higher loads may be more predisposed to an injury.9 Possible reasons for such asymmetries that could lead to higher load exposure are muscle weakness, impaired muscular coordination, and muscle strength imbalances.6

In addition, reduced capacity for force generation by the quadriceps and hamstrings can impair the control of knee joint at foot impact.10 Therefore, asymmetries in the hamstrings-to-quadriceps (H/Q) peak torque ratio may increase risk of injury for a given limb. This could happen if the hamstrings fail to decelerate (eccentrically) the leg,11,12,13 which increases, for instance, the loading on the anterior cruciate ligament (ACL) that assists in resisting tibial translation.14 Additionally, at high angular velocities (i.e. >180°·s⁻¹) greater conventional H/Q values were observed for highly trained runners than for recreational runners.15

Although isokinetic testing can be part of routine evaluation in competitive athletes, there is a lack of studies addressing symmetry or asymmetry in flexor to extensor torque ratios and peak torque in long distance runners. Flexor and extensor peak torque are possible to test in shorter protocols rather than considering multiple velocities or larger sets of repetitions. Therefore, such short protocols could be a strategy when screening for injury risk associated with limb asymmetries. The purpose of this study was to examine whether healthy and well-trained long-distance runners demonstrate symmetric performance during knee isokinetic testing at two angular velocities.

METHODS
Design and participants
Knee flexor and extensor torque, work and power were determined during isokinetic contractions of the quadriceps and hamstrings of both the lower limbs of long-distance runners. Symmetry was assessed by comparison between preferred and non-preferred limbs. Participants were informed of the study protocol, risks and possible harms as described in the consent form. Ethics approval for this research was obtained from the Ethics Committee for Research with Humans from the Federal University of Paraná (n° 0064.0.091.000-10).

Twenty-three healthy and well-trained male long-distance runners volunteered to participate in this study (mean ± standard deviation for age 18.0 ± 0.9 years old; height 1.73 ± 0.05 m; body mass 64.3 ± 7.9 kg; body mass index 21.38 ± 1.80 kg/m², and body fat of 11.63 ± 2.87%). They were free of injury or symptoms six months prior to the assessment. Average training patterns were six days per week and 70 km of training distance per week. Moreover, the individual average time for the 5 km distance event was 18.47 ± 1.15 min, as compared to the Olympic and World records of 12:57 and 12:37 min, respectively. Each runner reported to the laboratory for data collection in a single day.

Isokinetic evaluation
Right and left knee flexor and extensor torques were evaluated using an isokinetic dynamometer (Cybex NORM, Ronkonkoma, NY, USA). After warming up (5 minutes of treadmill running at self-selected pace), subjects were seated with their hips and thighs firmly strapped to the seat of the dynamometer, with the hip angle at 85°. The subjects were not allowed to hold the handles and hands were held across the chest during the testing. Dynamometer arm axis was visually aligned with anatomical axis of the knee joint. The shin pad attachment was placed 1 to 2 cm proximal to the subjects’ lateral malleolus.
The tests were repeated for the contralateral limb by recording the lever arm length, elevation of the dynamometer head and seat position for each subject by an experienced researcher (three years of experience in isokinetic testing). Gravity-correction procedure was performed according to manufacturer instructions.

During testing, the knee range of motion was 0-110° (0° indicates the knee being fully extended). The testing protocol consisted of open-chain isokinetic movements with concentric quadriceps and hamstrings contractions (3 repetitions at 60°·s⁻¹ and 5 repetitions at 240°·s⁻¹). Three submaximal repetitions were performed for familiarization, prior to testing at each speed. The variables analyzed were: peak torque (PT), total work (TW), power, and H/Q PT and TW ratios. PT, TW, and power were normalized to the subject's body mass.¹¹

Strength asymmetry index determination
Asymmetry index (AIₜₚ) was determined in order to describe the difference in PT, TW, and power between the preferred and non-preferred limb according to the Equation 1.¹¹ Negative AIₜₚ values indicate higher torque for the non-preferred limb.

\[
AI = \left( \frac{P \cdot NP}{P} \right) \cdot 100
\]

AI equals the percent asymmetry index, calculated by using the outputs for PT, TW, and power measurements of the preferred (P) and non-preferred (NP) limbs.

Statistical analysis
PT, TW, and power are presented as mean and standard-deviation (SD). Data normality was verified using the Shapiro-Wilk test. Limbs and angular velocities were compared using independent t-tests. The significance level was set at 0.05 for all comparisons.

RESULTS
Table 1 shows the mean and standard deviation valued for PT, TW, power, and H/Q PT and TW ratios. The differences were analyzed according to the limbs (preferred vs. non-preferred) and angular velocities (60°·s⁻¹ vs. 240°·s⁻¹). The knee flexor power output at 240°·s⁻¹ was significantly greater in the preferred compared to the non-preferred limb (p = 0.036). At 240°·s⁻¹ H/Q peak torque ratio was significantly higher in the preferred limb (p = 0.033), and at 60°·s⁻¹ significantly higher values were observed for H/Q total work ratio in the non-preferred limb (p = 0.021).

The AIₜₚ for PT and TW were similar across the different angular velocities for both knee flexion and extension (Table 2). However, the AIₜₚ for power at 240°·s⁻¹ were significantly higher compared to those at 60°·s⁻¹ (p = 0.035).

DISCUSSION
The results of the current study suggest that knee flexor power asymmetries exist among long-distance runners when assessed at the angular velocity of 240°·s⁻¹. Such results have important implications for long-distance running training and performance considering limb asymmetries as a potential risk factor for knee injury. Although the current results suggest that some asymmetry in muscle performance may exist, further investigation is needed to determine whether asymmetry increases injury risk.

The etiology of knee injury in runners is multifactorial.² Quadriceps and hamstring torques are related to the knee joint forces and moments (biomechanical factors) that may relate to causes of knee injury.¹⁶ Among runners, concentric isokinetic knee torque has been significantly correlated with patellofemoral (r = 0.60, p = 0.01) and tibiofemoral compressive forces (r = 0.68, p = 0.001)¹⁶, which are common injury sites in runners.¹ In addition, the extension peak torque at 60°·s⁻¹ and 240°·s⁻¹, and flexion/extension peak torque at 240°·s⁻¹ were significant discriminators of the anterior knee pain between injured and non-injured long distance runners.¹⁷ Knee flexor and extensor torque in long-distance runners is higher in the preferred limb, suggesting a functional asymmetry.⁶ The authors found higher flexor power for the preferred limb at 240°·s⁻¹ but not at 60°·s⁻¹ which suggests that contraction velocity may affect torque asymmetries. However, during isokinetic testing (open kinetic chain) the subject does not perform the specific movement of running (closed kinetic chain).¹⁸ The angular velocities used in the current study for isokinetic assessment did not represent the knee flexion angular velocity that
The neuromuscular system of long-distance runners is forced to perform asymmetrically in terms of mechanical adjustments to asymmetrical stimuli of the running environment such as the terrain, whereas for sprinters the non-preferred limb has a higher support function, requiring higher action of the knee extensors. It is possible that the training is observed during running tasks described by Hardin et al as being 400°·s⁻¹ to 600°·s⁻¹.

Additionally, different from what has been observed in sprint runners the authors did not find higher knee extensor power in the non-preferred limb. A possible reason for this difference may be due to the fact that the neuromuscular system of long-distance runners is forced to perform asymmetrically in terms of mechanical adjustments to asymmetrical stimuli of the running environment such as the terrain, whereas for sprinters the non-preferred limb has a higher support function, requiring higher action of the knee extensors. It is possible that the training

### Table 1. Mean ± standard-deviation peak torque (PT), total work (TW), knee flexors and extensors power (PO) and the hamstrings-to-quadriceps ratio (H/Q ratio) in preferred (P) and non-preferred (NP) limbs at the different velocities (60°·s⁻¹ and 240°·s⁻¹).

<table>
<thead>
<tr>
<th></th>
<th>flexors</th>
<th>extensors</th>
<th>H/Q ratio</th>
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<tbody>
<tr>
<td></td>
<td>PT (N·m·kg⁻¹)</td>
<td>TW (J·kg⁻¹)</td>
<td>PO (W·kg⁻¹)</td>
</tr>
<tr>
<td>60°·s⁻¹</td>
<td>P</td>
<td>NP</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>1.83 ± 0.36</td>
<td>1.72 ± 0.24</td>
<td>1.16 ± 0.20</td>
</tr>
<tr>
<td>240°·s⁻¹</td>
<td>P</td>
<td>NP</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>3.01 ± 0.36</td>
<td>2.83 ± 0.37</td>
<td>1.74 ± 0.21</td>
</tr>
</tbody>
</table>

* Difference between limbs (p<0.05).
† Difference between angular velocities (p<0.05).

<table>
<thead>
<tr>
<th></th>
<th>AI% Flexion</th>
<th>AI% Extension</th>
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<tr>
<td></td>
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<td>8.99</td>
</tr>
<tr>
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<tr>
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</tbody>
</table>

* Difference between angular velocities (p<0.05).
used by long distance runners may lead to different adaptations which may result in asymmetry, different than those seen in a sprinter, where training does not involve such high volume of running.

Asymmetries in peak isokinetic knee torque at 60°·s⁻¹ have been observed among professional (8.2 ± 11.3%) and junior basketball players (7.4 ± 9.3%), indoor volleyball and basketball players (9.1 ± 14.1%), and soccer players (3.4 ± 11.2%). It could suggest that bilateral limb strength differences may be sport-specific. For example, strength generated during preparation for a jump and absorbed during landing in volleyball can be uneven between lower limbs due to the specific characteristics of the sport movements. Additionally, athletes from sports with predominant unilateral movements are better in unilateral strength training exercises and may present more strength asymmetry as compared to athletes who practice sports with bilateral patterns of movements, such as running. Asymmetries in the lower limb have been considered as a risk factor for knee injuries as the incidence of ligament and muscle injury is up to 45% in those with asymmetry, as compared to only 20% in subjects without asymmetry. Among the reasons for this association between asymmetries and injury may be the fact that during landing either leg may receive higher loading. An athlete with asymmetric strength may experience higher loading in the weaker leg, and may not be able to support the impact, which may result in injury.

There is an effect of angular velocity on H/Q peak torque and total work ratios. At 240°·s⁻¹ H/Q peak torque ratio was higher in the preferred limb, and at 60°·s⁻¹ higher values were observed for H/Q total work ratio in the non-preferred limb. The values were 60% higher in both the angular velocities evaluated. The current results (~61% for both preferred and non-preferred limb) are similar to those described by Siqueira et al. for runners assessed at 60°·s⁻¹ showing a 56% H/Q peak torque ratio, and Portes et al. (58% H/Q peak torque ratio for both limbs at 60°·s⁻¹). The variability between these studies may suggest that when screening for injury risk among runners, considering two angular velocities for isokinetic testing might be helpful to assess for altered H/Q ratios and asymmetries. Furthermore, the current findings are in agreement with the concept that peak torque H/Q ratio is contraction velocity dependent (i.e. H/Q ratio increase as velocity increase).

When evaluating the H/Q total work ratio, runners seem to be more “balanced” than non-athletes. When evaluating the H/Q total work ratio, runners seem to be more “balanced” than non-athletes. The current findings suggest that runners are more “unbalanced” than jumpers, sprinters and non-athletes tested by Siqueira et al. However, compared to soccer and volleyball players, lower values of H/Q total work ratio were observed in the current sample of runners.

Chavet et al. suggested that asymmetries may have functional impact when asymmetry indexes exceeded 5%. However, previous authors who studied long-distance runners found higher Al in flexion and extension peak torque outputs at 60°·s⁻¹ (7.4 and 8.5%, respectively). Also, Al higher than 10% for muscle strength is common in long-distance runners. In the present study, no differences were observed for Al between angular velocities, except for flexor power output at 240°·s⁻¹ compared to 60°·s⁻¹ (Table 2). Kong and Burns found bilateral differences in flexor torque at 300°·s⁻¹ in healthy subjects, but not at 60°·s⁻¹ and 180°·s⁻¹. Similarly, Kobayashi et al. suggested larger asymmetries may occur at higher angular velocities to 180°·s⁻¹ than at 60°·s⁻¹.

Among the limitations of the current study is the lack of higher angular velocities during the testing session, which happened because the authors decided to utilize only low and intermediate velocities. Testing at velocities similar to those observed during running may provide further insight on the current topic. Additionally, this cohort study lacked a control group. Future research could benefit from the inclusion of a control group in order to provide baseline values for asymmetry in non-runners. Future research could also involve injured runners.

CONCLUSION

The results of the current study demonstrate that long-distance runners are asymmetric for isokinetic knee flexion (hamstring) power at 240°·s⁻¹. The highest of the two angular velocities tested elicited higher H/Q peak torque ratio in the preferred leg. These observations may have important implication for long-distance runners.
REFERENCES

ABSTRACT

Design: Cross-sectional, controlled laboratory study

Background: Lateral ankle sprains are common injuries and often lead to chronic ankle instability (CAI). Individuals who previously sustained a lateral ankle sprain, but did not develop CAI, termed copers, may have altered postural control strategies compared to individuals who have developed CAI. These altered postural control strategies may allow for more appropriate dynamic stabilization of the ankle joint after injury compared to those seen in patients who have developed CAI.

Objective: To compare lower leg biomechanics, as well as electromyographic (EMG) activation of the tibialis anterior and peroneus longus muscles, during the posteromedial reach of the Star Excursion Balance Test (SEBT) in individuals with healthy ankles, copers, and those with CAI.

Participants and Methods: 30 participants (12 control, 9 copers, 9 CAI) divided into three groups based on ankle sprain history and Cumberland Ankle Instability Tool score. Kinematic, kinetic, and EMG data were collected during three posteromedial reach trials on the SEBT.

Main Outcome Measures: Primary outcome measures include SEBT normalized reach distance in the posteromedial direction and average integrated EMG activation of the tibialis anterior and peroneus longus muscles during the reach. Secondary outcome measures included sagittal and frontal plane ankle complex angles and moments and sagittal plane knee angles and moments. Data were analyzed between groups using a one-way ANOVA model.

Results: No significant differences in reach distance or kinematic and kinetic outcomes were found between groups. The activation of the tibialis anterior and peroneus longus muscles was significantly different between groups (p = 0.033 and p = 0.014, respectively). The post-hoc analysis revealed that the coper group had significantly higher muscle activation compared to the control group, but not to the CAI group.

Conclusion: CAI did not alter kinematic, kinetic, or reach performance during the SEBT. When compared to controls, copers appeared to have greater activation of the ankle musculature, which may increase stability of the ankle complex during a dynamic balance task.

Level of Evidence: Prospective Cohort level II

Keywords: Copers, electromyography, motion analysis, Star Excursion Balance Test

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INTRODUCTION
The incidence of lateral ankle sprain has been estimated to be about 2.15 per 1000 person-years in at risk populations (e.g., athletes) in the United States.1 The rate of recurrence of lateral ankle sprains may be as high as 70% in active individuals,2 and approximately 40% of individuals with an initial lateral ankle sprain will develop longstanding ankle dysfunction (recurrent sprains, pain, and instability), also known as chronic ankle instability (CAI).3 The long-term consequences of CAI are still unknown, however, it has been postulated that both instability and recurrent sprains may damage the articular surface of the joint, thus increasing the risk of developing osteoarthritis.4

Evidence exists that postural control is altered after an acute lateral ankle sprain.5 While these postural control changes have been considered consequences of local proprioceptive deficits,6,7 recent evidence suggests that they may result from central motor control deficiencies.8,9 Authors have described that postural control is also impaired in the uninjured limb, suggesting that recurrent sprains may be the consequences of both centrally mediated deficits and local sensorimotor insufficiencies.10,11 Specifically, Hass et al.12 found that supraspinal motor control was altered in subjects with CAI to reduce the postural demand on the involved limb. This finding was supported by the work by Pietrosimone and Gribble,13 who found that corticomotor excitability was diminished in subjects with CAI. Discrepancies exist in the literature regarding postural control in individuals with CAI.5,14 Traditional tests used to assess postural control, such as single leg stance and center of pressure sway, have been shown to detect balance deficits in subjects following an acute lateral ankle sprain.5,10 However, injured subjects returned to their baseline in about four weeks,10 suggesting that these traditional tests, which are static in nature, may not be sensitive enough to detect longstanding CAI balance impairments.5 Balance deficits have been found in subjects with CAI during more challenging tasks such as jump landing15 and during the execution of the Star Excursion Balance Test (SEBT),16,17 suggesting that more dynamic balance testing scenarios should be studied. Additionally, inconsistent inclusion and exclusion criteria in establishing CAI may have led to these controversial results.5

The SEBT consists of a grid formed by eight lines made with athletic tape extending out at 45° arcs from each other in a star pattern.17 (Figure 1) Patients are asked to stand in the center of the grid with one leg and reach with the contralateral leg along each direction lines. The SEBT is a well-accepted clinical balance test which has been shown to be a valid and reliable test to identify dynamic balance deficits in patients with a variety of lower extremity conditions.18,19 The SEBT has been used to compare dynamic balance performance between subjects with CAI and healthy controls.16,17,20 Individuals with CAI reached a shorter distance in various reach directions on the SEBT when compared to uninjured individuals and when comparing the injured leg to the uninjured leg.16,17,21 Specifically, Gribble et al.16 reported that individuals with CAI had increased reliance on the proximal joints, and they completed the SEBT reach with greater peak flexion angles at the hip and knee joints compared to healthy controls. However, the authors did not report kinetic or surface electromyographic (EMG) measures, which limited their ability to fully detail the neuromuscular control strategies utilized by these individuals.

Not all individuals who laterally sprain their ankle develop CAI. This group of individuals, usually termed copers, can return to high functional activity without symptoms of CAI.22,23 Copers might have

Figure 1. Star Excursion Balance Test directions for a right test leg. Solid grey lines represent the reaching directions that are included also in the Y balance test. The solid black line represents the direction used in this analysis.
acquired alternative strategies to reduce the incidence of CAI symptoms. While results of studies that have investigated mechanical variables (i.e., joint laxity, joint stiffness, and fibular position) are inconsistent, subjects with CAI and copers were observed to have different balance strategies in terms of time-to-boundary during a single leg hop stabilization test and those with CAI had worse performance results. During more dynamic tasks such as jump landing and stepping down during continuous gait, copers were found to have greater activation of the tibialis anterior (TA) and peroneus longus (PL) muscles compared to those with CAI and controls.

EMG activation during reaching activities on the SEBT in individuals with CAI and copers has not been reported. Earl and Hertel reported that during the execution of the SEBT, activation of the lower extremity muscles differed between the various reaching directions in healthy individuals. The medial and posteromedial reach directions may impose higher demand on the ankle complex as they require the highest activation of the TA muscle. The posteromedial reach direction may be problematic for subjects with instability because it requires the trunk to move antero-laterally to compensate for the posteromedial reach. This movement might push the center of pressure toward the lateral edge of the foot, which can cause the foot to supinate. The posteromedial reach is also included in the Y-Balance Test™, which is a common balance test frequently used by rehabilitation clinicians. Therefore, to narrow the focus of the analysis, only the posteromedial reach was tested. The purpose of this study was to compare lower leg biomechanics, as well as EMG activation of TA and PL muscles, during the posteromedial reach of the SEBT in individuals with healthy ankles, copers, and those with CAI. It was hypothesized that copers would have higher activation of the ankle musculature compared to individuals with CAI and controls.

METHODS

Participants
Participants were recruited from both the general population and physical therapy practices. The study was approved by New York University's Institutional Review Board, and each participant gave informed consent before participating in the study. All participants met the following inclusion criteria: 1) were between 18 and 35 years of age; and 2a) had suffered at least one lateral ankle sprain (for CAI and coper groups) or 2b) had never suffered a lateral ankle sprain on either ankle (for the control group). Lateral ankle sprain was defined as an injury resulting from the ankle rolling, twisting or turning inward, which resulted in pain, swelling, and loss of function and/or participation in activity. Participants were excluded from this study if they had: 1) cardiovascular, pulmonary, neuromuscular and/or musculoskeletal diseases, disorders, or conditions that might interfere with motor performance; 2) undergone any lower limb surgeries; 3) suffered any musculoskeletal injuries within the past 6 months; or 4) consumed drugs and/or alcohol within 24 hours prior to testing that might interfere with motor performance. Additionally, participants that had poor plantar flexor muscle strength assessed via a standard single leg heel-rise-test on their test leg (subjects had to perform 25 repetitions with no limitations and minimal subjective fatigue) were also excluded to limit the possible confounding effect of muscle weakness on the SEBT performance. A customized questionnaire was used to determine: exclusion criteria; frequency and grade of previous lateral ankle sprains; whether treatment was sought after lateral ankle sprain; sport participation (hr/day); and presence of ankle pain during sport activities.

Group Placement
Perceived ankle stability was quantified using the Cumberland Ankle Instability Tool (CAIT), which is a valid and reliable (ICC = 0.96) questionnaire used to assess perceived symptoms of instability in different functional situations. A score (minimum 0, maximum 30) was then assigned based on the severity of the symptoms. Scores equal to or higher than 28 defined functionally stable ankles. Scores equal to or less than 24 defined functionally unstable ankles. Subjects with CAIT score between 24 and 28 were excluded from the study, although no prospective participants fell in this range.

Subjects were placed in one of three groups (CAI, coper, or control) based on history of lateral ankle sprain and perceived ankle stability as measured
with the CAIT score. Subjects in both the CAI and coper groups had a history of at least one lateral ankle sprain that resulted in swelling, pain, and temporary loss of function. Subjects included in the CAI group perceived their ankle as unstable (CAIT score equal to or less than 24). Subjects included in the coper group perceived their ankle as stable (CAIT score greater than or equal to 28). Subjects in the control group had never suffered a lateral ankle sprain on either ankle and perceived their ankle as stable (CAIT score equal to or greater than 28). Kinematic, kinetic, and EMG data were collected only on the stance leg during the SEBT, which was the injured leg for the CAI and copers groups. If a subject presented with bilateral instability (CAI) or injury (copers), the test leg was the one with the lower CAIT score. If a subject had equivalent bilateral ankle status (i.e., equal CAIT scores and/or injury rates), the test leg was determined by coin flip. The test leg in the control group was always determined by coin flip.

**Instrumentation**

**Kinematics**

Five Qualisys ProReflex cameras (Qualisys AB Inc., Gothenburg, Sweden) tracked the 3-dimensional position in space of reflective markers at 120Hz. A custom-made marker configuration was used. Ten individual reflective markers were placed bilaterally on the following locations: anterior and posterior superior iliac spines, two individual markers on the antero-lateral aspect of the thigh, and one on the lateral condyle of the femur. Six clusters of three reflective markers were adhered bilaterally to the shank, calcaneus, and first metatarsal (Figure 2). During the standing calibration trial, markers on specific anatomical landmarks (medial femoral condyle, lateral and medial malleoli, navicular bone, base of first metatarsal, and base of third metatarsal; Figure 2) were digitized using a digitizing wand in the Visual3D software (Version 4.0, C-Motion, Inc., Germantown, MD, USA). Joint centers and six-degrees of freedom models for the pelvis, thigh, shank, and foot were built using real and digitized markers in Visual3D, which were used for the kinematic and kinetic analysis.

**Kinetics**

One force plate (Kistler Inc., Winterthur, Switzerland) was used to acquire kinetic data during the SEBT testing. Analog data were collected at 1200Hz and analyzed in combination with kinematic information using the inverse dynamics algorithms in the Visual3D software. The center of the SEBT grid was aligned with the center of the force plate.

**Electromyography**

A Bagnoli-8 EMG system (Delsys Inc., Boston, MA, USA) was used to collect the EMG signals simultaneously with the kinematic and kinetic data. The activity of the TA and PL muscles, which control ankle movement in the frontal plane, was collected. The skin at each of the placement sites was shaved, abraded, and cleaned with an alcohol pad. For each muscle, one bipolar surface EMG electrode [DE 2.1 Single Differential Surface EMG Sensor, Delsys, Inc., Boston MA, USA; Sensor Contacts – 2 silver bars, 10 mm long 1 mm diameter; Contact Spacing – 10 mm; CMRR – 92 dB (typical), 84 dB (minimum)] was adhered on the belly of those muscles parallel to the direction of the muscle fibers. The ground electrode was placed directly above the spinous process of C7. A manual muscle test was performed to check for correct electrode placement and to check for crosstalk between muscles. An elastic wrap secured the electrodes and reduced the movement artifact. The electrodes remained affixed during all aspects.
of the test session. The EMG signals were acquired at a sampling rate of 1200 Hz and with a gain of 1000x [frequency response 20 ± 5–450 ± 50 Hz (80 dB/decade), System Noise (RTI) < 1.2 IV (RMS) for the specified bandwidth].

To allow for computerized measurement of the SEBT reach distance and to define SEBT reach events, a foot-switch was placed under the distal phalanx of the hallux of the reach leg and was used to track toe-off (TO - the instant the reaching foot was lifted from the ground to start the reaching task) and touchdown (TD - the instant the foot touched the ground along the specific SEBT line).

**Procedures**

Subjects were asked to stand barefoot with the navicular of their stance limb positioned over the center of the SEBT tape grid. The test was explained to each subject, as follows: they were asked to reach as far as possible along the posteromedial reach direction line with the reach leg, touch the ground lightly on the line with the most distal part of the reach foot without weight shifting, and return to the starting position while maintaining single-leg stance balance. Subjects were asked to keep the heel of the stance leg on the ground and their hands on their waist. Subjects were allowed to familiarize with the SEBT by performing three practice trials in the posteromedial reach direction.17 After subjects were equipped with markers and EMG electrodes, three posteromedial reaches were performed and kinematic, kinetic and EMG data were simultaneously recorded. During these trials, subjects were supervised to assure the trials were performed correctly and safely, while subjects were continually encouraged to reach as far as possible. Trials were discarded and performed again if subjects did not keep their hands on their hips or their stance heel on the ground throughout the trials. Data from the three reaching trials were averaged and used for the analysis.

**Data Analysis**

Raw kinematic, kinetic, EMG, and foot-switch data were imported to the Visual3D software for visual inspection and analysis. Coordinate reference systems for each segment were created in Visual3D, which were then applied to SEBT trials. The foot-switch data were visually examined to determine TO and TD for all SEBT trials. Specifically, the frame in which the force trace dropped to 0 was considered TO, while TD was defined as the frame in which the force trace rose above 0. The position data of all reflective markers were smoothed using a low-pass, 2nd order, zero-lag Butterworth filter with a cutoff frequency of 7Hz. Joint rotations were calculated to describe the movement of the stance leg during the SEBT reaches. To standardize the kinematic data, joint rotation angles are presented as the difference between the angle at TD and TO. Although the pelvis segment was created, the markers on the pelvis were obstructed during the SEBT reaches on numerous occasions. Thus, hip kinematic and kinetic data were not included in the analysis. To simplify the analysis at the knee, only sagittal plane kinematics and kinetics were calculated and analyzed, since that is where the majority of the motion occurred at that joint. At the ankle, both frontal and sagittal plane kinematics and kinetics were calculated and analyzed.

Kinetic data were smoothed (low-pass, 2nd order, zero-lag Butterworth filter with cutoff frequency of 20Hz) for the analysis. Dorsiflexion/plantarflexion and inversion/eversion moments at the ankle joint and flexion/extension moment at the knee joint were calculated. Joint moments were normalized to body weight (kg) and reported as the value at TD. All reported joint moments were external joint moments.

The EMG signals were filtered (band-pass, 2nd order, zero-lag Butterworth filter with cutoff frequencies of 20-450Hz), rectified, and smoothed (low-pass, 2nd order, zero-lag Butterworth filter with cutoff frequency of 7Hz). The maximal muscle activation of the TA and PL muscles during all SEBT trials was used to normalize the EMG signal between subjects.31 The integral of the EMG signal (area under the EMG curve) between TO and TD was calculated and used in the statistical analysis.

The reach distance during the SEBT was obtained by calculating the distance between the digitized markers on the navicular bone of the stance foot and the first metatarsal head on the reach foot at the instant the foot-switch was triggered by ground contact. Leg length was measured as the distance between the functional hip joint center (determined by using the validated functional joint center algorithm of Visual3D)32 and the virtual marker on the stance leg.
medial malleolus. This measure may provide a more accurate estimate of the actual leg length than using manual measurement of the distance between the anterior superior iliac spine (ASIS) and medial malleolus, which can be subject to error (e.g., presence of hip and/or knee flexion/extension contracture, examiner error, etc.). To validate this measurement, the distance between the markers on the ASIS and medial malleolus was calculated, and a correlation of 0.95 between the two measures (ASIS – medial malleolus vs Hip Joint Center – medial malleolus) was found. All SEBT reach distances were expressed as a percent of the leg length.

**Statistical Analysis**
A Shapiro Wilk’s test revealed that all data were normally distributed. Posteromedial reach distance, EMG activation and biomechanical variables were compared between groups using an individual one-way ANOVA for each variable. Tukey HSD post hoc test and effect size (Cohen’s $d$) were used to identify specific differences when significant group main effects were detected. Effect size was calculated using GPower software (version 3.1.2, University of Dusseldorf, Dusseldorf, Germany). The alpha level was set to 0.05, $a$-priori.

**RESULTS**
Thirty volunteers (17 male, 13 female, [mean ± SD] age = 26 ± 7 years, height = 1.71 ± 0.08 m, weight = 68.75 ± 13.09 kg) participated in the study. Based on the lateral ankle sprain history and CAIT score, 12 subjects were included in the control group and 9 subjects in both the coper and CAI groups. Demographic characteristics of the groups are reported in Table 1.

No significant between group differences were found for the SEBT reach and for kinematic and kinetic data (Table 2). However, the integral of the EMG signal of the TA and PL muscles were significantly different between groups (PL: $p = .014$; TA: $p = .033$, Figure 3). Compared to the control group, copers had significantly greater activation of the PL ($115\%$ increase, Tukey HSD $p = .013$, $d = 1.28$) and TA ($92\%$ increase, Tukey HSD $p = .031$, $d = 1.14$) muscles. Although not significant, the CAI group had $78\%$ ($d = 1.06$) and $61\%$ ($d = 0.95$) greater activation of the PL and TA muscles compared to the control group, respectively. Copers had approximately $20\%$ greater activation of the PL ($d = 0.35$) and TA ($d = 0.32$) muscles compared to CAI, but these results were not significant.

### Table 1. Subjects demographic data, mean (SD)

<table>
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<tr>
<th></th>
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<tr>
<td>Height, m</td>
<td>1.69 (0.07)</td>
<td>1.73 (0.09)</td>
<td>1.70 (0.11)</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>65.99 (11.82)</td>
<td>69.31 (12.74)</td>
<td>76.77 (20.42)</td>
</tr>
<tr>
<td>Leg Length, cm</td>
<td>81.32 (3.90)</td>
<td>80.68 (5.78)</td>
<td>81.54 (5.39)</td>
</tr>
<tr>
<td>Test leg LAS frequency</td>
<td>n/a</td>
<td>2.11 (1.62)</td>
<td>5.22 (3.15)</td>
</tr>
<tr>
<td>Doctor Visit for LAS, %</td>
<td>n/a</td>
<td>44</td>
<td>55</td>
</tr>
<tr>
<td>Grade of LAS (I,II,III)</td>
<td>n/a</td>
<td>2 (0.63)</td>
<td>2.17 (0.75)</td>
</tr>
<tr>
<td>Subjects Reporting Ankle Pain During Sport, %</td>
<td>8%</td>
<td>22%</td>
<td>77%</td>
</tr>
<tr>
<td>Sport Participation, hours per day</td>
<td>1.13 (0.48)</td>
<td>1.28 (0.36)</td>
<td>1.39 (0.33)</td>
</tr>
<tr>
<td>CAIT Score</td>
<td>29 (1)</td>
<td>28 (2)</td>
<td>18 (5)</td>
</tr>
<tr>
<td>CAIT Score range</td>
<td>28-30</td>
<td>28-30</td>
<td>10-24</td>
</tr>
</tbody>
</table>

Abbreviations: n/a, not applicable; LAS, lateral ankle sprain; CAIT, Cumberland ankle instability tool.
During a balance task, joint stability is maintained by a complex integration of passive (articular capsule and joint ligaments) and active (muscle and proprioception) elements. Following a lateral ankle sprain, the passive and active elements responsible for joint stability are often damaged. Based on the lack of injury history and their CAIT score, controls perceived their ankle as stable, and they required less muscle activation to maintain stability during the SEBT. The coper groups showed increases in PL and TA muscle activation compared to the control group, which might represent their compensatory strategy to provide dynamic joint stability during the SEBT following injury. However, due to the retrospective design of this study, it is unknown when this change in muscular control developed. These strategies may have been present prior to the lateral ankle sprain injury, although the patterns demonstrated by the uninjured control group suggested otherwise. It is possible that copers developed this mechanism after the first lateral ankle sprain, minimizing the likelihood of suffering from the symptoms of instability and subsequent injury. On the other hand, individuals with CAI had higher activation of the TA and PL muscle compared to control, but these results were not significantly different. The lack of difference in activation may suggest that individuals with CAI may not have fully developed this coping mechanism, which would put them at higher risk of recurrent sprains and instability. Future longitudinal studies should be designed to test these hypotheses.

**DISCUSSION**

A modified version of the SEBT was used to investigate dynamic balance performance and ankle muscle activation patterns in three groups (CAI, coper, and control). It was hypothesized that copers would demonstrate higher activation of the tested ankle muscles than controls and those with CAI while reaching on the SEBT. The results partially support this hypothesis as copers had greater activation of the TA and PL muscles only when compared to the control group, but not when compared to the CAI group. The greater activation of the TA and PL muscles may improve the control and stability of the ankle complex during the SEBT.

**Table 2.** Star excursion balance test (SEBT) reach, kinematic and kinetic data for the postreomedial direction. SEBT reach is reported as percentage of leg length. Kinematic data are reported as difference between angle at touchdown and toe-off. Kinetic data are reported as value at touchdown.

<table>
<thead>
<tr>
<th></th>
<th>Controls</th>
<th></th>
<th></th>
<th></th>
<th>Copers</th>
<th></th>
<th></th>
<th></th>
<th>CAI</th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>95% CI</td>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>95% CI</td>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>95% CI</td>
</tr>
<tr>
<td>SEBT reach, %</td>
<td>79.1</td>
<td>8.7</td>
<td>73.6</td>
<td>84.6</td>
<td>84.2</td>
<td>4.4</td>
<td>80.8</td>
<td>87.6</td>
<td>82.9</td>
<td>11.4</td>
<td>74.1</td>
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<tr>
<td>angle, °</td>
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<tr>
<td>Ankle eversion angle</td>
<td>7.36</td>
<td>4.09</td>
<td>4.76</td>
<td>9.95</td>
<td>9.78</td>
<td>4.05</td>
<td>6.68</td>
<td>12.89</td>
<td>11.25</td>
<td>6.23</td>
<td>6.46</td>
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<tr>
<td>Knee flexion angle,</td>
<td>44.72</td>
<td>15.12</td>
<td>35.12</td>
<td>54.33</td>
<td>44.55</td>
<td>2.82</td>
<td>42.54</td>
<td>46.57</td>
<td>38.62</td>
<td>10.57</td>
<td>30.50</td>
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<tr>
<td>Ankle dorsiflexion</td>
<td>0.25</td>
<td>0.23</td>
<td>0.11</td>
<td>0.39</td>
<td>0.31</td>
<td>0.12</td>
<td>0.21</td>
<td>0.40</td>
<td>0.27</td>
<td>0.18</td>
<td>0.13</td>
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<tr>
<td>moment, Nm/BW</td>
<td></td>
<td></td>
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<tr>
<td>Ankle eversion</td>
<td>0.33</td>
<td>0.09</td>
<td>0.28</td>
<td>0.39</td>
<td>0.39</td>
<td>0.14</td>
<td>0.28</td>
<td>0.50</td>
<td>0.38</td>
<td>0.12</td>
<td>0.29</td>
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<tr>
<td>moment, Nm/BW</td>
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<td></td>
</tr>
<tr>
<td>Knee flexion</td>
<td>1.47</td>
<td>0.29</td>
<td>1.28</td>
<td>1.65</td>
<td>1.41</td>
<td>0.28</td>
<td>1.20</td>
<td>1.62</td>
<td>1.30</td>
<td>0.30</td>
<td>1.06</td>
</tr>
<tr>
<td>moment, Nm/BW</td>
<td></td>
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Abbreviations: SD= standard deviation, C.I.= confidence intervals, LB= lower bound, UB= upper bound, SEBT= Star Excursion Balance Test, BW= body weight.

**Figure 3.** EMG activation of the peroneus longus and tibialis anterior in the control (black bars), copers (dark grey bars), and CAI (light gray bars) groups; *, indicates significant difference between groups; **, indicates significant difference between control and coper group.
The higher activation of the TA muscle is particularly important due to the nature of the posteromedial SEBT task. The SEBT is a closed kinetic chain activity, and while the foot is still on the ground, the shank is moving over the foot. The closed chain eversion measured in all groups during the SEBT, relates to a lateral displacement of the shank over the foot. At the same time, the external forces acted on the lateral side of the ankle as suggested by the external eversion moment. This kinematic and kinetic pattern is potentially dangerous as it may generate a lift of the medial side of the foot off the ground, making the lateral edge of the foot a fulcrum about which an inversion sprain can occur.24,28,34 This is especially important in the posteromedial SEBT reach, as individuals shift their trunk anterolaterally during that task in order to counteract the posteromedial reach and maintain the center of pressure within the base of support (stance foot). Therefore, increased activation of the TA muscle, may be needed to control the lateral displacement of the shank in a closed chain position.24,28,34 Gutierrez et al.24 found that a coper group had high activation of the TA before landing on a pneumatic platform that produced a supination perturbation. Similarly, Dun-das et al.26 found that copers had higher activation of the TA muscle when negotiating a curb during gait. In the current study, copers had higher activation of the TA throughout the reaching movement on the SEBT, which, combined with greater peroneal activation, may help copers better control and stabilize the ankle during dynamic tasks.

Another interesting, yet controversial, finding was that no reach differences between the groups were found. Previous authors16,17,21 found that subjects with CAI reached significantly less when standing on the affected leg compared to the unaffected leg and compared to a separate group of uninjured controls. The SEBT performance involves several neuromuscular systems and consequently may be affected by a variety of factors such as muscle strength, flexibility, and activity level.35 In the CAI group of the current study, the standard deviation and range of scores on the CAIT showed that these individuals had varying disability levels, which may explain the more variable SEBT performance relative to the coper and control groups, who presented with less variability in disability level (i.e., CAIT score) and more consistent SEBT performance. The exclusion of participants with poor plantarflexor strength and the constraints placed by the position of the foot-switch under the distal phalanx of the hallux may have also contributed to the absence of any difference in reaching performance observed in this study.

The inconsistent results regarding the presence of SEBT reach deficits in subjects with CAI may also be related to the criteria used to define CAI. All three studies16,17,21 that found significantly lower SEBT reach distances in subjects with CAI, used the following as the definition of CAI: 1) ankle sprain and “giving-way” history, 2) no ankle sprain within 6 weeks, and 3) multiple sprains and “giving-way” within the past 12 months. On the other hand, the studies that did not find differences in SEBT reach (Sefton et al.35 and the current study) defined CAI using a validated questionnaire, along with ankle sprain history. Sefton et al.35 required CAI subjects to report difficulties in more than one area in the Functional Ankle Instability Index (FADI) or two areas in the FADI sport. In the current study, the CAI subjects had to score 24 or less in the CAIT. These discrepancies indicate that the CAI group may not be homogenous among these studies and highlight the need for standard criteria to define CAI, including greater consistency in patient-reported functional outcomes and quantitative tests, which may help in obtaining more consistent findings among different studies.5,33,36

**STUDY LIMITATIONS**

The small sample size and unequal group sizes are considered limitations of this study. Rehabilitation participation following the lateral ankle sprain was not assessed, so it is unknown whether copers naturally changed their motor strategy or if the change was due to a rehabilitation program. The placement of reflective markers and EMG electrodes may have generated a movement constraint that affected the SEBT performance. This might also explain the lack of difference of reaching distance relative to the previous published studies.16,17,21 In addition, subjects were asked to reach as far as they could, but it is unknown whether they actually reached their true maximum throughout the testing.

**CONCLUSIONS**

The purpose of this study was to assess lower leg kinematic and kinetic patterns, as well as TA and PL
muscle activation during the posteromedial reach of the SEBT in subjects with healthy ankles, copers, and individuals with CAI. The results of the current study indicate that perceived ankle stability status did not alter kinematics, kinetics, and reaching performance during the posteromedial reach on the SEBT. Compared to controls, copers appeared to use a strategy involving greater activation of the TA and PL muscles, which may be needed to increase control of ankle stability during the posteromedial reach of the SEBT following an ankle injury.

REFERENCES


ABSTRACT

Background: Hip arthroscopy is a common surgical technique for the correction of intraarticular pathology. While surgical success is often determined by anatomical correction, post-operative rehabilitation serves an essential role in restoring pre-morbid activity levels. A paucity of long-term post-operative rehabilitation outcomes exists in the literature lending uncertainty to the long-standing efficacy of interventions and associated risk for future injury.

Case Description: This case report describes the progress of a male subject 3.6 years after left hip arthroscopy with labral repair. Detailed clinical measures and insight into potential risk factors are presented as a follow-up to a previously published case report.

Outcome: A 3.6-year follow-up assessment revealed potential risk factors that may have predisposed the subject to future pathology. The most profound finding was the subject's complaint of contralateral right hip pain and examination findings suggesting intraarticular pathology. His left surgical hip presented with no reported problems or significant findings. The examination also revealed an anterior tilted pelvis, muscle length deficits, and hip muscle weakness which may have contributed to his right hip pain or may be risk factors for future pathology in both hips. It appeared that these impairments affected his gait and performance on functional tests.

Discussion: This case report describes the 3.6 year follow-up for a young adult male subject after unilateral left hip arthroscopy and acetabular labral repair. The re-examination findings and risk factors identified at the follow-up may provide insight into the need for long-term surveillance among post-surgical individuals. Detailed reporting of the long-term effects of a post-operative program after hip arthroscopy is non-existent in the literature and the current findings suggest the potential need for mitigating risk in the non-surgical hip. Future longitudinal studies are needed to develop a consensus on the best interventions for these patients.

Keywords: Femoral acetabular impingement; hip; impingement

Level of Evidence: 4-Case Report
BACKGROUND

Hip arthroscopy has become a common surgical technique for correction of hip intraarticular pathology. Hip arthroscopic procedures have increased in the United States between 2004 and 2009 with a reported incidence rate of 1.2 cases per 10,000 in 2004 to 5.58 cases per 10,000 in 2009. The rate of surgical complications remains low with a reported 0.58% incidence and a reoperation rate of 6.3%, with the most common reason being a conversion to total hip arthroplasty. The surgical technique may include single or combination of procedures such as: correction for femoral acetabular impingement (FAI), labral debridement or repair, chondroplasty, osteoplasty, microfracture, synovectomy, repair of the ligamentum teres, treatment for capsular hyperlaxity, and loose body removal.

Post-operative rehabilitation is an essential component for helping patients return to pre-morbid athletic activity after surgery. Often, the patient will follow a structured rehabilitation program based upon the operative procedures and surgeon specific guidelines. Several authors have presented a structured intervention program in clinical commentaries but a consensus on the optimal evidence based post-operative rehabilitation program does not exist. Moreover, post-operative management has not been investigated in a comparison based trial suggesting there is little basis for the superiority of one approach versus another. This paucity of evidence may be due to procedural variability given the potential for numerous procedures that may be performed during an arthroscopic surgery. A recent systematic review appraised the literature investigating postoperative programs after hip arthroscopy and reported that post-operative programs are under investigated with only case reports (level 4 evidence) available to guide clinical practice. There seems to be a lack of long term follow-up among the evidence. There was only one manuscript that reported a follow-up greater than one year. Bizzini et al followed patients for an average of 2.7 years post-operatively and reported the time period when the individuals regained symmetrical range of motion (ROM), pre-injury level of hip and core strength, and return to sport. Unfortunately, the authors in the aforementioned study did not provide any data for these clinical measures. These methods of reporting are consistent with the literature reporting hip arthroscopic post-operative outcomes, which often provide little details of the rehabilitation program and specific outcome measures. This leaves a gap in current understanding of the long-standing effects of post-operative rehabilitation programs and which interventions influence recovery. More detailed longitudinal reporting of the effects of post-operative rehabilitation would provide clinicians with the necessary information to determine the best immediate and long-term strategies for their patients.

Along with the need for reporting the long-term effects of post-operative rehabilitation, a good long-term prognosis would seem to be dependent upon clinicians having the necessary information to recognize, identify, and address apparent risk factors for future or recurring pathology. Several authors have reported potential risk factors which include radiographic findings, postural deviations, pelvic positions, gait kinematics, muscle length deficits, and poor hip muscle strength. Also, several authors have found a correlation between FAI and lumbopelvic issues such as osteitis pubis, athletic pubalgia, and lumbosacral issues. It has been suggested that these concomitant injuries are caused by stresses across the lumbopelvic region due to compensatory movements from mechanical hip pain.

To date, there is little epidemiological data regarding the risks for future or recurrence of FAI after surgery. One recent study examined the regrowth rate of the femoral cam lesion after osteoplasty for FAI. Gupta et al conducted an average two-year follow-up on a group of 47 patients (N = 28 males, 19 females). The authors found no recurrence of CAM deformity based upon pre and post-surgical radiographic examination. However, one cannot surmise that a two-year follow up would provide definitive long-term insight beyond this timeline.

For the clinician, recognizing the connection between potential risk factors and the recurrence rates for intra-articular pathology would seemingly offer a prognostic benefit to patients. Current research is emerging and a clear consensus of how to prevent future or recurring FAI remains under investigation. Despite the growing popularity of hip
arthroscopy, there is a disparity between the surgical procedure and consensus for the optimal postsurgical rehabilitation program. In 2012, the authors published a case-report detailing a four-phase rehabilitation program for an 18-year-old male high school athlete who underwent arthroscopic surgery for a left hip mixed cam-pincer FAI with an anterior superior acetabular labral tear. The aforementioned case report had, both one and four month follow-up reports with detailed clinical measures. The purpose of this case report is to report the progress of the subject at a 3.6 year follow-up with details of the re-examination and insight into potential risk factors.

CASE DESCRIPTION
A subject that was initially treated in 2011, following a left hip arthroscopy, was seen via direct access for a recent onset of right hip pain. Reexamination was performed by the same physical therapist (SWC) in 2014, approximately 3.6 years after his 2011 arthroscopic left hip surgery. Details from the initial case report are reviewed and new findings are presented from the current examination followed by a discussion on the current findings and insight into risk potential.

Patient History and Treatment (2011)
At the time of the initial examination, the subject was a healthy 18-year-old male high school athlete with a mixed endomorphic-mesomorphic build (body mass=92.53 kg, height= 182.9 cm, body mass index=27.7kg/m²) who underwent arthroscopic surgery for a left hip mixed FAI with an anterior superior labral tear in March 2011. The subject participated in high school American football (at the free-safety position) and reported an insidious onset of left hip and groin pain for one year prior to formal diagnosis. Diagnosis was confirmed by magnetic resonance arthrogram (MRA) (3TesLar from Philips®, Andover, MA) which revealed a left mixed cam-pincer FAI with an anterosuperior labral tear. The subject's symptoms were recalcitrant to physical therapy, activity modification, and medical management. The surgical intervention included an acetabular and femoral head osteoplasty & chondroplasty, a capsular synovectomy, and an anterior superior labral repair via two arthroscopic portals. The subject's primary goals were to return to pain-free physical activity and begin college football in the fall. The patient underwent a comprehensive initial examination and four-phase treatment program that is detailed in an earlier publication.

Discharge (2011)
The subject met all goals and was discharged after completing 16 weeks of physical therapy. The subject reported 0/10 pain on the numeric pain rating scale (NPRS) with activities of daily living, weight training, and sports activity (e.g. jogging, football drills). The Flexion-Adduction-Internal Rotation (FADIR) test was also negative for signs of hip impingement in both hips (Table 1). The subject had active and passive pain-free hip ROM in all motions. Manual muscle testing of both hips and lower extremities were graded at a 5/5 (normal) for all muscle groups tested (Table 2). Muscle length testing using the Ober test, 90/90 hamstring test, Ely test for rectus femoris length, and Thomas test was normal except for mild left hip flexor tightness confirmed with the Thomas test. The subject presented with a normal gait and no visible lower kinetic chain deviations during single leg and multidirectional activity demonstrated by little to no compensatory movements at the hip, knee, and ankle (Table 1). Shortly after discharge, the subject was cleared by his surgeon to begin advanced sports specific and agility training in preparation for the next football season at the collegiate level.

One and Four Month Post Discharge Follow-Up
At the one month re-examination, the subject reported 0/10 pain with sports specific training, weight-lifting, agility training, and jogging. The FADIR test was also negative for signs of hip impingement. Bilateral active and passive hip ROM in all motions was still normal. The subject did present with a left positive 90/90 hamstring and Thomas test that revealed decreased muscle length (Table 1). Manual muscle testing of both hips, knees, and ankles was graded at a 5/5 (normal) (Table 2). The subject still presented with a normal bilateral gait pattern and no visible lower kinetic chain deviations with bilateral, single leg, and multidirectional movements. The subject was advised of the decreased muscle length in the left hip region and educated on the need for flexibility activities.

At the four month follow-up, the subject had reduced his body mass to 83.91 kg and presented with an
observable mesomorphic build. The subject had continued full pain-free (0/10) unrestricted activity that included running, power lifting, and football training at college. The re-examination revealed a negative FADIR test and normal bilateral active and passive hip ROM in all motions. Bilateral muscle length was normal. Manual muscle testing of both hips, knees, and ankles was graded at a 5/5 (normal) (Table 2). The subject continued to present with a normal gait pattern and no observable lower kinetic chain deviations with bilateral, single leg, and multidirectional movements (Table 1).

**Outcomes: Three-Year Follow-up**

**Subject History**

A re-examination was conducted approximately 3.6 years after the subject's left hip arthroscopic surgery due to a recent onset of right hip pain after activity. The subject presented as a healthy 21-year-old with a mesomorphic build (body mass-86.18 kg, height- 182.9 cm, body mass index-25.8). The subject had finished his collegiate football experience in 2013 and was still a student finishing his degree coursework. The subject reported participating in
episode of care in 2011. Lower extremity ROM was measured using a standard goniometer. Normal bilateral active and passive hip ROM was observed except for right hip flexion (100°) and internal rotation (30°). The subject demonstrated a guarding response at the end range of those motions. Muscle length was assessed using the Ober test, 90/90 hamstring test, Ely test for rectus femoris length, and Thomas test for one-joint hip flexors. The subject presented with a bilateral positive 90/90 hamstring, Ely, and Thomas tests revealing decreased muscle length. Manual muscle testing (without dynamometer) revealed bilateral weakness in the hip flexors, extensors, abductors, internal rotators, external rotators, and knee flexors (Table 2).

Observational gait assessment revealed no major sagittal or frontal plane deviations on the left. The right lower extremity demonstrated a shortened stride slowing the patient's walking cadence. Functional testing identified visible deviations through the lower kinetic chain in both lower extremities. During repeated bilateral squats, the subject limited the descent angle to approximately 80 to 90° of knee flexion due to pain (3/10) in the right anterior hip region. During the single leg squat, the subject's right leg demonstrated a valgus collapse between approximately 45 and 60° of knee flexion with a reported 3/10 hip pain as the knee angle reached approximately 80° where the subject stopped. The left knee also demonstrated a valgus collapse between approximately 60 to 90° with no pain. During multidirectional toe touching, the subject demonstrated increased trunk sway and valgus deviation for both legs in the frontal plane and oblique angles (Table 1). The subject was only able to squat to a depth of 45 to 60° on the right leg and 90° with the left. Special testing was conducted last due to the new complaints reported by the subject. The examiner conducted the FADIR (Figure 2) and flexion-abduction-external rotation (FABER) test to assess for a suspected intra-articular hip pathology. Both tests were positive on the right hip reproducing the subject's concordant pain and were negative on the left hip.

Assessment and Decision-Making
The re-examination revealed decreased active and passive ROM in the right hip, bilateral muscle length

Re-Examination
A static standing posture screen revealed a moderate sway back (Figure 1) with an observable anterior tilted pelvis which was a new finding since initial weight training, jogging, and recreational sports (e.g. basketball) with 0/10 pain in his left hip. However, the subject did report a 3/10 pain in his right hip with the activities noted above after 30 minutes of participation. Pain was described as a "deep right groin pain" that was similar to his left hip with an insidious onset over the prior three months with no known mechanism. The pain would resolve with rest. Mechanical hip symptoms such as "clicking" and "popping" were also reported during physical activity or twisting movements. The subject was unable to reproduce the symptoms when asked during the examination. A systems review and neurovascular screen were inconclusive for medical red flags in both lower extremities as presentation was entirely mechanical.
The subject was symptomatic in one hip, he may have been predisposed to bilateral deformity. Macguffin et al.\textsuperscript{15} found that the contralateral hip may be predisposed to cartilage degradation in individuals with bilateral CAM deformity who have unilateral hip pain. These findings may not have been identifiable at the time of his initial diagnosis several years prior. The subject has since been referred back to the surgeon for examination of the right hip which may provide more insight into these contralateral hip findings.

**Postural Deviations**

The subject's anterior tilted pelvis may be a potential risk factor. Ross et al.\textsuperscript{19} found that anterior pelvic tilting resulted in significant acetabular retroversion and a decrease in femoral internal rotation in 90° of flexion and 15° of adduction. The authors' concluded that an anterior tilted pelvis was a predictor for earlier occurrences of FAI due to the influence the position has on the functional orientation of the acetabulum. Ida et al.\textsuperscript{42} also found that subjects with both cam-type FAI and acetabular dysplasia assumed a greater anterior tilted pelvis when in standing. The authors concluded that these morphological issues may induce secondary symptoms in these patients.\textsuperscript{42} Clinician's should be aware of the assumed pelvic positions, such an anterior pelvic tilting, in patients with FAI due to the possible implications it may have on the patient's symptoms and risk for future pathology.

**Gait Deviations**

The re-examination revealed muscle length deficits and bilateral hip weakness which may have affected the subject's gait and could be potential risk factors or influence the progression of an existing intra-articular hip pathology. Kennedy et al.\textsuperscript{22} observed gait differences in hip abduction, sagittal and frontal plane hip ROM in subjects with FAI when compared to a control group. Based on their findings, they suggest that these differences may be caused by soft-tissue restriction in the hip and decreased frontal pelvic ROM (anterior tilted pelvis) resulting from limited lumbosacral mobility.\textsuperscript{22} Other case studies\textsuperscript{43-46} have reported muscle length deficits, soft-tissue, and joint restrictions around the hip and lumbopelvic region in subjects diagnosed with FAI and labral tears. The correlation between muscle length deficits and the onset of FAI still needs to be more thoroughly inves-
tigated, however, should be considered during the clinical examination.

The weakness in this subject's hip flexors, abductors, and extensors may have had an influence on the patient's hip control during gait and functional activities. Casartelli et al. reported hip flexor weakness in patients with symptomatic FAI. Lewis et al. also found that patient with FAI demonstrated decreased force of the gluteal muscles during hip extension and the iliopsoas during hip flexion which increased the forces across the anterior hip. Hunt et al. observed kinematic and kinetic differences in patients with symptomatic FAI. Patients exhibited a significantly slower cadence, kinematically peak hip extension, adduction, and internal rotation during stance. Patients with FAI also exhibited less peak hip flexion and external rotation moments when compared to a control group. These findings were consistent with the subject's right hip which have also been observed in other investigations.

**Functional Testing**

Poor performance during lower extremity functional movements may have been related to muscle weakness and heavily influenced by a combination of pain and fear. The onset of the subject's right hip pain may have induced a fear avoidance reaction, which could explain some of the observed findings. This would not be unreasonable given the last episode of left hip pain resulted in a surgical procedure. Mannion et al. found that the top two pre-operative reasons for patients elective for FAI included: "alleviation of pain" and "fear of worsening." Patients also tend to limit their motion during activity in the presence of pain. Limitations in hip flexion motion have been observed during squatting activities and gait in individuals with symptomatic FAI. Patients with FAI also tend to restrict their motion in directions of hip joint impingement.

Despite these observed findings, it must be acknowledged that several years had passed since the subject had been following post-operative guidelines and was motivated to return to his sport. At the time of the re-examination, the subject was physically active but had not been adherent with his original post-operative program. This subject may have benefitted from a more structured preventative program since the date of discharge. The examination findings in the right hip support the fact that the subject may have been predisposed to bilateral hip impingement and that his current hip pain was affecting his function.

The main limitation of this case report is that the clinical examination from the prior publication was reproduced in order to have a direct comparison between follow-up sessions. The original case report only used the NPRS to measure pain and did not include patient related outcome measures. Clinicians are encouraged to use patient related outcomes (PRO's) throughout the rehabilitation process in order to obtain a more objective, repeatable measurement of their patient's progress. There are many PRO's available for clinicians to use. Some of the more common questionnaires for non-arthritic pathology in young to middle age adults include: Copenhagen Hip and Groin Outcome Score (HAGOS), Hip Outcome Score (HOS), International Hip Outcome Tool-33 (IHOT-33) and IHOT-12 (Short version). During the prior study, there was no hand held dynamometer or isokinetic device used to assess muscle strength or torque production, which would have provided a more objective measurement of the subject's muscle performance. Therefore, during the current re-examination, muscle strength was tested without a dynamometer. Hip ROM in the prior study was measured with a standard goniometer which again was used in the re-examination to maintain intra-rater reliability. For clinicians, the use of a digital inclinometer versus standard goniometry is preferred due to the enhanced accuracy of the device. These factors must be considered when interpreting these finding for clinical practice. Clinicians are encouraged to use valid and reliable patient related outcome measures and digital devices for muscle testing and ROM in order to obtain the best objective measures.

**Clinical Relevance**

The re-examination findings and postulated risk factors are meant to highlight an understudied area and provide the clinician with potential risk factors based on the current evidence. One can surmise from the reported findings that the younger male subject may have been at risk for bilateral abnormal hip morphology since 2011. Also, his anterior tilted pelvis, muscle length deficits, and hip muscle weakness.
ness may have contributed to his additional complaints of right hip pain or may be risk factors for future pathology in both hips. It appears that these impairments may have affected his overall gait and performance on functional tests. The main concern is the subject’s recent onset of right hip symptoms and suggestion of intra-articular pathology. While the subject originally returned to high-level activities, risk factors may have existed to suggest the need for on-going, longitudinal monitoring after hip arthroscopy. Several authors have found a correlation between hip FAI and osteitis pubis, athletic pubalgia, and lumbosacral issues which may be due to the excessive stress created through the lumbopelvic region during compensatory movements. The research in this area is still emerging. Currently, there is little epidemiological data on risk factors for further damage after hip arthroscopy or chances of getting a second FAI. There may not be enough longitudinal data to reveal any trends. Only surgical complications have been reported in the literature.

CONCLUSION
This case report is the first to document a 3.6 year follow-up for a young adult male subject after unilateral hip arthroscopy and acetabular labral repair. The re-examination findings and postulated risk factors are unique to the subject, which must be considered when interpreting these findings for clinical practice. The detailed reporting of the long-term effects of a post-operative program after hip arthroscopy has not been reported in the literature. This case report presented the longitudinal finding and compared them to the current literature. Several potential risk factors were discussed that could have an influence on the occurrence of future pathology or concomitant injury but all of these need to be studied using other research methods. This understudied topic leaves a gap in the current knowledge on the effectiveness of post-rehabilitation after hip arthroscopy. Clinicians and researchers are encouraged to conduct longitudinal follow-ups on their patients in order to assess the long term effects of the interventions.

REFERENCES


ABSTRACT

Background and Purpose: Chronic lateral hip and thigh pain is regularly treated by the physical therapist. Many issues can cause pain in this region, and trigger points may contribute to pain. Dry Needling (DN) is an intervention used by physical therapists where a monofilament needle is inserted into soft tissue to reduce pain thereby facilitating return to prior level of function. The purpose of this case series is to report the outcomes of DN and conventional physical therapy as a treatment intervention for subjects with chronic lateral hip and thigh pain.

Case Descriptions: Four subjects with chronic lateral hip and thigh pain attended between four and eight sixty-minute sessions of dry needling and stretching/strengthening activities over a four to eight week intervention course. Outcomes were tested at baseline and upon completion of therapy. A long-term follow up averaging 12.25 months (range 3 to 20 months) was also performed. The outcome measures included the Visual Analog Scale (VAS) and the Lower Extremity Functional Scale (LEFS).

Outcomes: The LEFS and VAS indicated clinically meaningful improvements in disability and pain in the short term and upon long term follow up for each subject. The LEFSmean for the four subjects improved from 50.75 at baseline to 66.75 at the completion of treatment. At long-term follow-up, the LEFSmean was 65.50. Each subject met the minimal clinically important difference (MCID) and minimal detectable change (MDC) for the LEFS and the VAS. The VAS was broken down into best (VASb), current (VASC), and worst (VASC) rated pain levels and averaged between the four subjects. The VAS improved from 20 mm at the initial assessment to 0 mm upon completion of the intervention duration. The VASb improved from 25.75 mm to 11.75 mm, and the VASC improved from 85 mm to 32.5 mm. At the long-term follow up (average 12.25 months), the VASb, VASC, and VASC scores were 0 mm, 14.58 mm, and 43.75 mm respectively.

Discussion: Clinically meaningful improvements in pain and disability were noted. Subjects reported improved sleep and functional mobility, which were commensurate with their different age ranges and initial reported limitations in mobility. The results of this case series show promising outcomes for the use of dry needling in the treatment of chronic lateral hip and thigh pain. Further controlled clinical trials are recommended to determine the effectiveness of adding dry needling as compared to other interventions for chronic lateral hip and thigh pain.

Level of Evidence: Level 4.

Keywords: Dry Needling, hip pain, iliotibial band, trochanteric bursitis
BACKGROUND AND PURPOSE

Dry needling (DN) effectiveness research continues to be important in the therapy community regarding the use of DN as a treatment strategy for various conditions. Currently, no randomized control trial (RCT) studies exist investigating the effectiveness of DN treatment of pain of the lateral hip and thigh. Recent systematic reviews regarding the effectiveness of dry needling for TrPs and myofascial pain syndromes have been conducted and demonstrate some positive clinical responses to DN interventions. Cagnie et al recommend the use of DN for neck pain with moderate evidence, though there is weak evidence for improved function and quality of life.1 Kietrys et al recommend DN versus sham or placebo needling for decreasing pain immediately and at a four-week follow-up for individuals with myofascial pain syndrome.2 Tough et al on the other hand, did not find statistically significant evidence that DN was superior to sham or placebo interventions based on their meta-analysis, but noted limitations to the review included small sample sizes and poor methodological qualities of the reviewed studies.3 Tough et al did note that the use of DN “could” be a positive direction for the treatment of myofascial pain syndrome, but larger, higher quality studies were needed.

TrPs have been studied as a source of pain, and the most accurate way to identify a likely TrP consists of palpation of a tender nodule in a taut band of muscle with subject pain recognition of tender spot palpation.4 The ability of a clinician to accurately diagnose a TrP location using palpation lacks clinical reproducibility, which is due to the inability to palpate the specific location of a TrP.4,5 Sciotti et al and Myburgh et al have shown positive inter-rater reliability for TrP identification in the upper trapezius muscle if the examiners were experienced.6,7 The problem with these studies is that small sample sizes were utilized and Myburgh et al showed that pairing experienced and inexperienced examiners caused a reduction in identification of TrPs.8 Hong et al and additional authors continue to promote the local twitch response (LTR) as being necessary for maximum effectiveness of trigger point dry needling (TrP-DN), yet there is much debate regarding the necessity of the LTR.9 Tough et al suggest that of the original four criteria most commonly used to diagnose TrPs (LTR, predicted pain referral pattern, palpable tender nodule in a taut band of tissue, and reproduction of pain symptoms), LTR and predicted pain referral pattern are no longer essential for diagnosis.4 It should be noted that commonly, both myofascial DN and TrP-DN terminology is being used to denote types of DN intervention, yet DN is not just limited to myofascial pain or TrP intervention. DN may be used to treat peri-neural conditions, myofascial TrPs, intramuscular conditions, symptomatic scar tissue and other various conditions that might benefit from the use of DN. The current terms used, including “myofascial” DN or “TrP” DN, may be too restrictive for the multitude of conditions and tissues that can be treated with DN. Regardless of these issues, interventions described in this case series were focused on treating myofascial TrPs in the painful regions reported by the subjects in the case series.

Lateral hip and thigh pain may be the result of various etiologies including, but not limited to: osteoarthritis of the hip joint, greater trochanteric bursitis (GTB), iliotibial band syndrome (ITBS)/ snapping hip syndrome, muscle weakness/ strength imbalances, flexibility deficits, friction issues, spinal pathology, and leg length discrepancies.11-20 GTB is often commonly used as a label by medical providers to identify lateral hip pain. GTB is most likely to occur between the fourth and sixth decades of life, though cases in all age groups have been reported in the literature.21 Trochanteric pain syndrome was originally thought to be caused by inflammation of the trochanteric and/or sub-gluteus maximus bursa (i.e. bursitis), but authors of recent MRI and ultrasound studies question the idea that bursitis is the etiology for all trochanteric regional pain.18 A more general term, greater trochanteric pain syndrome (GTPS) includes a number of disorders of the lateral, peri-trochanteric region of the hip, including trochanteric bursitis, gluteus medius and minimus tears, and external coxa saltans (snapping hip).19 The incidence of GTPS is reported to be approximately 1.8 subjects per 1000 per year, with the prevalence being higher in women, and in subjects with coexisting low back pain, osteoarthritis, ITB tenderness, and obesity.20 Symptoms include persistent pain in the lateral hip radiating down the lateral thigh to the knee, and occasionally into the buttock region.
Physical examination typically indicates point tenderness in the posterolateral area of the greater trochanter.\textsuperscript{20}

Iliotibial band (ITB) involvement, typically associated with lateral knee pain, commonly presents concurrently with GTPS in the author's clinical experience. According to the literature, the lateral knee region is the most extensively researched and identified area of ITB pain pathology, but clinically it is common to have palpable tenderness along the entire length of the ITB. There is minimal published evidence that describes effective treatment strategies for ITBS. Treatments vary greatly and commonly include non-steroidal anti-inflammatory drug (NSAID) administration, phonophoresis, corticosteroid injections, deep friction massage, and correction of hip strength abnormalities.\textsuperscript{13,14} Given the inconsistency with accurate diagnosis of the etiology of chronic lateral hip and thigh pain, the possibility of TrP formation in the affected hip and thigh musculature is plausible. Clinical presentation of palpable tender nodules in taught bands of tissue and subject recognition of pain pattern supports this as a possible etiology. Though the ITB and GT region are not considered to be muscular in nature, many surrounding muscles are closely linked to the ITB and GTB regions, which could be sources of pain contribution.

Given the lack of research supporting diagnostic criterion and treatment strategies for lateral hip and thigh pain, there is a need for the documentation and presentation of clinically effective interventions that can improve pain, thereby improving general function present due to chronic pain. The purpose of this case series was to investigate DN coupled with conventional physical therapy (CPT) as a treatment strategy for subjects with chronic lateral hip and thigh pain.

**CASE DESCRIPTIONS**

This case series included four subjects with chronic lateral hip and thigh pain of duration > 90 days. Specific questions were asked to each subject, and included thorough questioning about sleep deficit due to pain when lying on the affected hip, mobility limitations associated with pain, and any limping mechanics during gait that may not have been observed upon presentation to the clinic. A review of subject histories found common functional deficits including difficulty sleeping due to pain caused by rolling onto the affected side, and limited functional mobility due to pain affecting walking tolerance > 5 to 10 minutes in duration. The subjects were all in good relative health without serious underlying pathology. They could each ambulate independently without an assistive device, though three out of four reported intermittent limping due to pain. All four subjects had been previously treated by physicians and physical therapists for interventions including, but not limited to: corticosteroid injections and/or “traditional” physical therapy interventions including stretching and exercise activities, light and deep friction tissue mobilization (such as foam rolling and massage/myofascial release techniques), and therapeutic ultrasound. Subjects had not been treated for at least one year prior to the intervention for this case series. Temporary relief was reported with the previous treatment strategies, but pain was not eliminated and there was no long-term improvement per subjective reporting by each of the subjects.

**CLINICAL IMPRESSION 1**

Given the fact all four subjects had previous treatment consisting of CPT, and ongoing lateral hip and thigh pain since that time, the subjects were considered appropriate for inclusion in the case series to examine the effectiveness of adding DN to a CPT program. An examination of each subject was performed in order to assess common functional limitations, strength deficits, gait impairments, and to rule out serious neurovascular pathology that might require referral to another medical specialist based upon findings.

**EXAMINATION**

Examination took place at baseline, and upon completion of the therapy intervention period. The number of treatment sessions and duration of treatment depended on each subject’s response to the intervention. The number of treatment sessions ranged from four to eight. Treatment was not rendered > 8 weeks due to maximal measureable improvement being attained by each subject during that time frame.

Posture and gait mechanics were assessed. Posture assessment included observation of lumbar, innominate, and global spinal positioning, and observation of gait mechanics. Physical examination of each of
The subjects revealed no to mild loss of lumbar lordosis, but given the layers of tissue covering the lumbar region, accurate palpation and observation of lumbar spinal curvature was difficult and found to be unreliable in each of the subjects. The ability to accurately assess pelvic symmetry with static or movement-based positioning testing is generally believed to lack validity or reliability, therefore palpation assessment for positional faults of the SIJ were not performed.22-24 No other postural abnormalities were noted.

Bilateral lower extremity (BLE) strength was assessed via manual muscle testing (MMT) in a short sitting position with the hips and knees flexed and the legs hanging off the table. Strength was not being measured as an assessed outcome for change in this case series, thus the manual muscle testing scores are not noted within. It was noted that all four subjects had mild bilateral hip abduction, extension, and hip flexion strength deficit, which was scored between 4 to 4+ out of a possible 5, with hip abductors and extensors being the weaker of the hip muscle groups consistently demonstrated between the four subjects.

A lower quarter neurological examination was performed to screen each subject for spinal origin symptoms. This included dermatomal, myotomal, and deep tendon reflexes (DTRs). Dermatomal testing assessed light touch sensory palpation to the T10-S2 dermatomal regions of the trunk and lower extremities. Myotomal testing was assessed via MMT of the same nerve root representations just mentioned. DTRs were assessed via testing of the L4 and S1 nerve roots in short sitting at the patellar tendon and Achilles tendon bilaterally. Bilateral knee and ankle DTRs were normal in all subjects. Seated slump testing (sensitivity = 0.84; specificity = 0.83)25 was performed to assess for neural tension/ lumbar disc involvement, and was negative in all subjects. There were no neurovascular abnormalities noted. It is noted that one subject did have a pacemaker, and therefore did not receive electrical stimulation applied to the needles as part of the intervention. This will be discussed later in the case series discussion section.

Symptom centralization testing for pathology of discogenic origin has been found to be valid and reliable.26 Subjects were tested via repeated flexion and extension movements in standing for periperalization/ centralization phenomenon, which was negative for discogenic pain in all subjects. Sacroiliac joint (SIJ) involvement was ruled out using a test cluster as suggested by Van der Wurff et al27 as well as the active straight leg raise (ASLR) as described by Mens et al28 Van der Wurff identified the following cluster of five pain provocation tests: ASIS distraction and compression, Gaenslen, thigh thrust, and Patrick tests. A cutoff of three or more positive tests has the highest positive likelihood ratio of 4.02 (sensitivity of 85%, specificity of 79%, positive predictive value of 77%, and negative predictive value of 87%).27 All tests of the SIJ were negative for all subjects.

Palpation assessment revealed tender nodules in taut tissue bands and subject pain recognition in the vastus lateralis muscles and greater trochanteric bursa areas in each subject, suggesting possible TrPs in the affected musculature. The locations and number of tender nodules varied and were located throughout the affected regions in each subject in no particular pattern. There were no autonomic responses noted (e.g. temperature change, diaphoresis, etc.) and no sensory issues were identified. Trophic changes of the skin were also absent in all subjects.

Range of motion (ROM) was not assessed, as this case series was focusing on pain, changes in patient self-report of functional mobility, and subjective reports of dysfunction such as sleep deficit.

**CLINICAL IMPRESSION 2**

Based upon examination findings, all four subjects were deemed appropriate to receive the intervention described in the “Intervention” section of the case series report. There were no contraindications that would preclude any of the four subjects from the application of DN and CPT. All subjects reported no previous limitations in sleep, mobility, or general function prior to the onset of their hip and thigh pain conditions. All four subjects had ongoing lateral hip and thigh pain affecting their daily activity tolerance and sought long-term pain relief, which they had not received with prior treatment. Hip and thigh pain coupled with negative contraindications for DN intervention made the subjects appropriate for DN to be performed.

**OUTCOME MEASURES**

The outcome measures used in this case series were the Lower Extremity Functional Scale (LEFS) and
The LEFS was used to assess functional disability. The lower the score the greater the disability. The LEFS is a quick and reliable patient self-report functional outcome tool that can be easily completed and has been found to be a reliable and sensitive to change when compared to the SF-36, with a minimal detectible change of 9 points and the minimal clinically important difference of 9 points. Test-retest reliability per Watson et al was found to be high (for

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
<th>Subject 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEFSa Baseline</td>
<td>70/80</td>
<td>51/80</td>
<td>46/80</td>
<td>36/80</td>
</tr>
<tr>
<td>LEFS Final</td>
<td>80/80</td>
<td>60/80</td>
<td>67/80</td>
<td>60/80</td>
</tr>
<tr>
<td>LEFS Follow-Up</td>
<td>80/80</td>
<td>58/80</td>
<td>58/80</td>
<td>66/80</td>
</tr>
</tbody>
</table>

**Table 1. Outcome Measure Scores at Baseline and Upon Completion of Treatment**

**LEFS Baseline**

- Best: 20
- Current: 61
- Worst: 90

**LEFS Final**

- Best: 11.75
- Current: 14.58

**LEFS Follow-Up**

- Best: 12.75
- Worst: 43.75

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
<th>Subject 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>VASb (mm.) Baseline:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Best: 0 30 20 30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current: 0 12 61 30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Worst: 60 90 90 100</td>
<td></td>
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</tr>
</tbody>
</table>

| VAS (mm.) Final: |
| Best: 0 0 0 0 |
| Current: 0 7 3 1 |
| Worst: 0 4 4 5 |

| VAS (mm) Follow-Up: |
| Best: 0 0 0 0 |
| Current: 0 1 0 0 |
| Worst: 0 4 4 35 |

| LEFS Baseline mean: 50.75/80 |
| VAS Baseline mean (Best): 20 |
| VAS Final mean (Best): 0 |
| VAS Follow Up mean (Best): 0 |

| LEFS Final mean: 66.75/80 |
| VAS Baseline mean (Current): 25.75 |
| VAS Final mean (Current): 11.75 |
| VAS Follow Up mean (Current): 14.58 |

| LEFS Follow Up mean: 65.50/80 |
| VAS Baseline mean (Worst): 85 |
| VAS Final mean (Worst): 12.75 |
| VAS Follow Up mean (Worst): 43.75 |

a LEFS: Lower Extremity Functional Scale
b VAS: Visual Analog Scale
as listed in Table 2 prior to DN, without variation from one subject to the next.

The needles used in this case series were solid monofilament Seirin J-type sterile needles (Seirin Corp., 1007-1 Sodeshi-Cho, Shimizu-ku, Shizuoka-shi, Shizuoka 424-0036 Japan), No. 8 (0.30 diameter) x 50 mm. Needles were held in the therapist's dominant hand for application and manipulation of the needle within the tissue. Before needle insertion, an application of 70% isopropyl alcohol was performed to the areas and allowed to dry for at least ten-seconds, which reduces the resident micro-flora of the skin by 80-91%.34 All DN interventions were performed according to the Dry Needling Institute (DNI) of the American Academy of Manipulative Therapy (AAMT) Fellowship training program.34 The DNI program does not focus specifically on TrP-DN, as some other DN training programs do, however, the DNI does include TrP-DN as one of several treatment strategies for DN, hence this is the basis for this specific treatment strategy for this case series. The electrical stimulation unit used to apply current to the needles was an AWQ-104L digital electro-acupuncture scope, four-channel, eight-lead device (Lahasa OMS, 230 Libbey Parkway, Weymouth, MA 02189).

DN of the greater trochanteric bursa regions was performed as shown in Figure 1. Needles were inserted lateral to medial in the center of the greater trochanteric region to an approximate depth of 40 to 45 mm. Needles were wound clockwise to attain needle grasp of the between the needle and soft tissue, and left in-situ for 15 minutes. DN techniques, including needling winding, may have a local and/or remote therapeutic effect based on mechanical coupling of connective tissue and the needle thereby causing a "downstream" effect on the generation of a mechanical signal caused by needle grasp pulling. These downstream effects may include cell secretion, modification of extracellular matrix, enlargement and propagation of the pain signal along connective tissue planes, and afferent input modulation by changes in the connective milieu.35-38

DN of the vastus lateralis/ ITB region was performed with four 30-mm. needles as demonstrated in Figure 1. Flat palpation was used to first identify multiple tender points throughout the midline of the lateral thigh. Once the initial needle was inserted into the

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.34 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.34 There we no reported contraindications by the subjects that would prevent the use of DN.

Subjects were treated with CPT interventions including traditional stretching and strengthening exercise activities and a specific DN protocol focusing on the painful region of the hip and thigh. Informed consent to participate in the series was retrospectively obtained from the subjects. Human subjects research review was not required for this case series. Subjects were advised that all HIPPA protected health information standards would be upheld and none of their identifying information would be released per the policies and procedures of the clinic where the treatment was performed.

The subjects were treated for four to eight sessions, one to two times per week for up to eight weeks. Subjects were positioned in side lying with a pillow between their knees on a hi-low table for subject and therapist comfort. The following soft tissues were treated: approximate mid center of the greater trochanter, and five along the lateral thigh (in either the ITB or the vastus lateralis), with each needle spaced four fingerbreadths distal to the previously inserted needle for a total of six needles. The location of the needles were determined based on the author's clinical experience of performing DN to lateral hip and thigh pain, and this has become a semi-standardized approach to the application of DN for this condition in the author's private practice. Each subject performed the CPT exercise program exactly
### Table 2. Examples of Conventional Physical Therapy Activities

<table>
<thead>
<tr>
<th>Variable</th>
<th>Intervention</th>
<th>Duration</th>
<th>Illustration(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Therapeutic stretching</strong></td>
<td>1. Seated hamstring stretch</td>
<td>1. 3 x 20 sec. bilateral</td>
<td>See appendix A for images of stretches and exercises utilized in the case series.</td>
</tr>
<tr>
<td></td>
<td>2. Supine hip abduction stretch</td>
<td>2. 3 x 20 sec. bilateral</td>
<td></td>
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<tr>
<td></td>
<td>3. Supine ITB stretch with belt</td>
<td>3. 3 x 20 sec. bilateral</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. 4-way resisted straight leg raise</td>
<td>4. 1 or 2 sets of 15 reps w/ resistance from 2-4 lbs. bilateral</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. Standing gastrocnemius stretch</td>
<td>5. 3 x 20 sec. bilateral</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. Standing soleus stretch</td>
<td>6. 3 x 20 sec. bilateral</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. Resistance band “clams”</td>
<td>7. Side-lying bilateral with band color either green or blue</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8. Supine bridge</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9. Body weight squats</td>
<td>8. 2 sets of 15 reps</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11. Step ups</td>
<td>10. 2 sets bilateral for 20 feet with band color either orange or green</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>11. 2 sets of 15 reps bilateral</td>
<td></td>
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</table>
by pain reduction, reduction in disability level, and through subjective reports of improvement in the subject’s general daily activity tolerance. At baseline and upon completion of the intervention, pain and disability were assessed via the VAS and LEFS outcome measures. As noted earlier, objective measures such as hip strength, though mildly deficient, were not assessed as an outcome being measured indicating improvement. The reason for this was that strength deficit was not a reported deficit noted by the subjects; hence the outcomes were not looking to improve strength specifically, rather pain primarily. The results of these outcome measures are shown in Table 1. An average of the outcome measure scores were used to measure the overall improvement in pain and disability levels, as this gives a general representation of improvement between the four subjects. Each subject met the MCID and MDC for the LEFS as shown in Table 1. The final LEFS scores upon completion of the intervention ranged from 60 to 80 points versus the initial range of 36 to 70 points. The mean improvement between the four subjects demonstrated a mean improvement from 50.75 at baseline to 66.75 at completion of treatment, which at sixteen points, is well above the MDC/MDIC indicating clinically meaningful improvement.

At long term follow up (average of 12.25 months after completion of the treatment sessions), the LEFS average score was 65.50.

The VAS scores were broken down into reported best (VAS\textsuperscript{b}), current (VAS\textsuperscript{c}), and worst (VAS\textsuperscript{w}) levels. Individual VAS ranges were as follows: VAS\textsuperscript{b} at baseline, scores ranged from 0 mm to 30 mm and improved to 0 mm for all four subjects at completion of treatment. The VAS\textsuperscript{c} ranged from 0 mm to 61 mm and improved to 0 mm to 7 mm upon completion. The VAS\textsuperscript{w} scores at baseline ranged from 60 mm to 100 mm and improved to 0 mm to 40 mm upon completion. A mean was then calculated to average the four subject’s scores for ease of interpretation. The mean VAS\textsuperscript{b} score improved from 20 mm to 0 mm (at completion of treatment). The mean VAS\textsuperscript{c} improved from 25.75 mm to 11.75 mm. The mean VAS\textsuperscript{w} improved from 85 mm to 32.5 mm. At follow up, the mean VAS\textsuperscript{b} was 0 mm, the mean VAS\textsuperscript{c} was 14.58 mm, and the mean VAS\textsuperscript{w} was 43.75 mm. All four subjects verbally reported subjective reports of improved sleep, walking tolerance, and general improved tolerance to daily activities upon completion of treatment.

**OUTCOMES**

The demographic characteristics of the subjects are outlined in Table 3. The efficacy of DN was measured greater trochanteric region, five subsequent needles were inserted four fingerbreadths distal to each prior needle insertion location. The most distal needle was inserted to a depth of approximately 10-15 mm, depending on the amount of tissue per subject, in order to avoid joint insertion. The needles were rotated clockwise to attain needle grasp and left in-situ for 15 minutes.

The use of electrical stimulation applied to the needles was performed according to the following parameters outlined by the DNI\textsuperscript{34} 2 Hz, 250 microseconds, continuous asymmetric biphasic square wave with negative spike at an intensity described by the subjects as “mild to moderate”. As a side note, one subject was not treated with electrical-stimulation of the tissues via the needles due to having a pacemaker, which may have contraindicated this portion of the intervention. Call bells were left with each subject receiving DN.

**Figure 1.** Example of DN placement for treatment. Most proximal needle is placed over the greater trochanter, while each subsequent needle is placed approximately 4 fingerbreadths distal to the previous needle, in the middle of the ITB.
and at the follow-up. Sleep, walking tolerance, and general function was noted as limited prior to initiation of treatment. At the long-term follow up, there were no significant reports of functional limitations reported by any of the four subjects.

DISCUSSION
Clinical results were positive, indicating improvements in pain and disability per the outcome measures used in this case series. Subjective reports of improved sleep, walking tolerance, and daily activity tolerance were also reported at follow up. All subjects reported specific improvements such as walking tolerance with no intermittent limping, which was a common presentation prior to intervention. There was one subject who received DN without the use of electrical stimulation due to having a pacemaker, and this subject also demonstrated remarkable improvement in reported pain and disability per the outcome measures. It should be noted that studies comparing the use of DN with and without electrical stimulation should be performed in the future, as there are no current studies examining DN alone versus DN with electrical stimulation in the treatment of lateral hip and thigh pain.

There are limitations to case series research. The small sample size (n = 4) is an inherent limitation to a case series, though results are more clinically meaningful than a single case report. Given the lack of randomization and no specific inclusion or exclusion criterion, only descriptive outcomes can be reported, and statistical analysis cannot be inferred or provided. The small sample size also makes generalization of the intervention difficult, though the four subjects in the series were typical subjects seen in everyday practice and not statistically broken down to fit a certain criterion-based inclusion. Also, all four subjects performed CPT exercises that may have contributed to the overall positive outcomes, which makes it difficult to determine how much of the improvements were specifically attributable to DN and how much were attributable to the exercise program prescribed. Larger randomized control studies looking at DN interventions need to be performed in order to fully assess the effectiveness of DN as an intervention strategy for GTPS and/or ITB etiologies. Further research is recommended in order to determine if DN is clinically beneficial independent of, or coupled with other therapeutic interventions, such as other “manual” therapy techniques including “myofascial release” and massage or non-thrust mobilization. Another area of further research should also compare the use of DN with electrical stimulation versus DN alone.

CONCLUSIONS
CPT and DN were tolerated well by the subjects, demonstrating improvements in pain and function, without significant adverse effects. Given the clinically meaningful reduction in pain and improvements in reported function, the addition of DN to CPT for chronic lateral hip and thigh pain etiologies shows promise. Future higher level research is needed to fully explore the effectiveness of DN for lateral hip and thigh pain.

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APPENDIX A
Images of Common Physical Therapy (CPT) Activities

Seated Hamstring Stretch

Supine Hip Abduction Stretch

Supine ITB Stretch with Belt

4 Way SLR: flexion

4 Way SLR: Abduction

4 Way SLR: Adduction

4 Way SLR: Extension

Standing Gastrocnemius Stretch

Standing Soleus Stretch

Resistance Band Clams

Supine Bridge

Body Weight Squats

Resistance Band Side Step

Step Ups

ITB=Iliotibial band; SLR= straight leg raise
ABSTRACT

Achilles Tendinopathy is a complex problem, with the most common conservative treatment being eccentric exercises. Despite multiple studies assessing this treatment regime little is known about the mechanism of effect. This lack of understanding may be hindering therapeutic care and preventing optimal rehabilitation. Of the mechanisms proposed, most relate to tendon adaptation and fail to consider other possibilities. The current consensus is that tendon adaptation does not occur within timeframes associated with clinical improvements, therefore the clinical benefits must occur through another unidentified pathway. This clinical commentary critically reviews each of the proposed theories and highlights that muscle alterations are observed prior to onset of Achilles Tendinopathy and during the disease. Evidence shows that the observed muscle alterations change with treatment and that these adaptations have the ability to reduce tendon load and thereby improve tendon health. The purpose of this clinical commentary is to review previous theories regarding the mechanisms by which eccentric exercise might affect Achilles tendinopathy and offers a novel mechanism by which the plantarflexor muscles may shield the Achilles tendon.

Keywords: Achilles, eccentric exercise, efficacy, Tend*

Level of Evidence: 5

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INTRODUCTION AND BACKGROUND
Tendinopathies of the Achilles tendon affect 2% of the general adult population, with a prevalence in active individuals between 9-40% depending on the type and level of sporting activity investigated. Exercises that load the tendon are promoted as being beneficial for tendinopathy with isolated eccentric exercises receiving the most attention. In recent years researchers have attempted to determine the clinical effectiveness of eccentric exercises, most authors reported successfully returning 60% of participants back to sport, which contrasts with the 100% reported to have returned to sport in Alfredson's original paper. The lower success rates observed in later trials is thought to be due to a poorer response to isolated eccentric exercises in non-athletic and female individuals when compared with athletic subjects. A recent systematic review confirmed the success of eccentric exercises, however, the mechanism by which the effect is achieved remains unclear; and an understanding of this may help the development of an optimal treatment regime and improve patient care.

The most commonly suggested mechanism through which eccentric exercises are believed to have an effect is the application of increased loads to the tendon stimulating structural tendon changes. Despite the many studies investigating eccentric intervention regimes the mechanism of effect remains in question, although the original concept proposed by Stanish and Curwin and later Alfredson et al still remains the most popular. This concept suggested that greater load in the tendon occurs during eccentric training and this stimulates the tendon to undergo structural adaptation, sometimes referred to as “hypertrophic” change. In response to this theory several authors have explored tendon change occurring during and after eccentric exercises using magnetic resonance imaging (MRI) and Ultrasound (US). Tendon structure was shown to have been altered with rehab but this was after extended periods of time, often years. Further work has shown that eccentric exercises do not place greater strain on the Achilles tendon when compared with concentric exercises suggesting that this mechanism may not be involved. The overall suggestion from current literature and a recent systematic review supports the notion that tendon structure does not significantly change during the treatment period and that changes do not correspond to improvements in pain or function. When viewed together these results clearly suggest that clinical improvements during rehabilitation occur through a mechanism distinct from structural adaptation.

MECHANISM OF EFFECT OF ECCENTRIC EXERCISES
This section will review each of the proposed mechanisms for effect of eccentric exercise on Achilles tendinopathy presented in Table 1 and outline the current evidence for each.

| Table 1. Proposed mechanisms of effect of eccentric exercise on Achilles tendinopathy |
|---------------------------------|-------------------------------|
| Structural tendon adaptation    | Structural tendon adaptation  |
| Tendon length changes           | Tendon length changes         |
| Neuro-vascular ingrowth         | Neuro-vascular ingrowth       |
| Neuro-chemical alterations      | Neuro-chemical alterations    |
| Fluid movement                  | Fluid movement                |
| Neuromuscular adaptations       | Neuromuscular adaptations     |

**Structural tendon adaptation**
Despite the many studies investigating eccentric intervention regimes the mechanism of effect remains in question, although the original concept proposed by Stanish and Curwin and later Alfredson et al still remains the most popular. This concept suggested that greater load in the tendon occurs during eccentric training and this stimulates the tendon to undergo structural adaptation, sometimes referred to as “hypertrophic” change. In response to this theory several authors have explored tendon change occurring during and after eccentric exercises using magnetic resonance imaging (MRI) and Ultrasound (US). Tendon structure was shown to have been altered with rehab but this was after extended periods of time, often years. Further work has shown that eccentric exercises do not place greater strain on the Achilles tendon when compared with concentric exercises suggesting that this mechanism may not be involved. The overall suggestion from current literature and a recent systematic review supports the notion that tendon structure does not significantly change during the treatment period and that changes do not correspond to improvements in pain or function. When viewed together these results clearly suggest that clinical improvements during rehabilitation occur through a mechanism distinct from structural adaptation.
the tendon length remains the same. It is unclear why increasing the length of the muscle tendon unit (MTU) would alleviate tendon pain, and while some suggest that tendon loads may be diminished, there is no corroborating evidence for this suggestion. An alternative explanation is that the addition of sarcomeres shifts the length tension curve thereby allowing the muscle to generate greater force later in its range,\textsuperscript{14,56} which would theoretically allow the muscle to decelerate eccentric loads and offload the tendon.\textsuperscript{57,58} The concept of muscle(s) being able to offload non-contractile tissue is not new but is infrequently considered in AT.\textsuperscript{58} This will be considered in greater detail later in the commentary. Observations of reduced DF in patients with AT may in fact be related to plantarflexor muscle weakness as suggested by Mueller et al\textsuperscript{59} in their study assessing DF ROM during the gait cycle. Their data suggest that individuals with reduced plantarflexor torque reduce their DF range of motion, in order to maximize their plantarflexor moment during gait.\textsuperscript{59} This effectively suggests that the measurement of DF range of motion is not the issue, and that the real issue may rest with plantarflexor muscle strength (torque/power).

Muscle-tendon unit stiffness

Often associated with length of the tendon is the concept of tendon stiffness (or lack thereof). The current suggestion is that making the muscle tendon unit more flexible (less stiff) is a desirable aim. It is unclear from the current literature why a reduction in tendon or muscle stiffness would benefit the tendon. Several studies have shown reduced tendon stiffness when comparing AT patients with healthy controls.\textsuperscript{60,63} Few researchers have examined the effect of eccentricities on stiffness. Mahieu et al\textsuperscript{53} tested stiffness of the MTU prior to and after an eccentric training regime and showed both an increase in weight bearing DF ROM and a reduction in passive stiffness of the MTU\textsuperscript{53}, however this stiffness change was attributed to muscle rather than tendon adaptation. In contrast, Morrissey et al\textsuperscript{64} have shown that eccentric exercises increase tendon stiffness. The contrasting results observed by Morrissey et al and Mahieu et al may be a result of differing ankle joint moment calculations and also different sample sizes. Sugiaski and co-authors recently showed that the force of plantarflexor contraction directly influences Achilles tendon stiffness,\textsuperscript{65} unfortunately this has not been accounted for in any of the studies measuring or modelling tendon stiffness making it very difficult to accurately understand in-vivo tendon stiffness in healthy or diseased tendons.

Neuro-vascular in-growth

The initial research findings of Ohberg and Alfredson (demonstrated strong correlations between the quantity of neuro-vascular in-growth and pain in subjects’ Achilles tendons).\textsuperscript{21} Further work showed that obliteration of these vessels through sclerosant injections,\textsuperscript{56,67} high volume saline injections,\textsuperscript{68-70} or more recently “paratenon scraping” produced excellent clinical outcomes.\textsuperscript{71,72} Researchers then examined whether eccentric regimes altered these neo-vessels and reported that after 12 weeks of eccentric exercises the neuro-vascular ingrowth was reduced\textsuperscript{23} and the hypothesis was this reduction in neo-vessels directly leads to pain reduction. The mechanism proposed for this was shear forces between paratenon-fascial-tendon layers, which was damaging the microvascular circulation.\textsuperscript{23} Recently, authors highlighted that neurovascular bundles in muscles and tendons are important for load transmission, suggesting that a loading modality (eccentric or otherwise) may influence the neurovascular bundle and thereby possibly affect neovascularisation. However, whether this effect is beneficial or not needs further examination.\textsuperscript{73} It is important to note later studies determined a lack of correlation between pain and vascularity either as a predictor of recovery\textsuperscript{74} or as a direct measure of outcome\textsuperscript{27,75} suggesting these measures may be of little use.

NEURO-CHEMICAL INTERACTION

Heinemeier et al demonstrated a dose dependent effect of load on production of chemical mediators in tendon, and that this response does not vary when comparing concentric or eccentric contractions.\textsuperscript{76} These neuro-chemical changes occur as a result of alterations in tenocyte activity reducing various chemicals and messenger molecules involved in pain sensitivity (various neurotransmitters).\textsuperscript{28,29,77,78} Attia et al recently showed glucosaminoglycans (GAG’s) may be involved in tendon pain.\textsuperscript{79} Attia et al found a strong correlation between GAG content and pain and function.\textsuperscript{79} Interestingly, laboratory work
has highlighted that increases in GAG concentration leads to mechanical hypersensitivity of nociceptive neurons suggesting a possible pathway for the involvement of GAGs on pain.\textsuperscript{80} this sensitivity coupled with the increased number of nerves in pathologic tendons\textsuperscript{78,81-84} may explain some of the tissue hypersensitivity clinically observed. Eccentric loading has been shown to reduce the volume of the Achilles tendon more than concentric loading, as measured using MRI.\textsuperscript{31} This volume change was thought to be due GAG content and may account for the associated pain reduction observed with loading.\textsuperscript{11}

The role that the central nervous system may play in tendinopathy has also been addressed,\textsuperscript{85} and animal studies have shown a clear link between tendinopathy in one limb and changes in the opposite limb.\textsuperscript{86} Similar findings have also been identified in humans with surgery on one limb improving the contralateral symptomatic tendon.\textsuperscript{37} Several authors have proposed that this finding is not related to limb use but rather changes in CNS output.\textsuperscript{85,88} How exercise treatments may influence this remain to be investigated and further research is necessary.

**Fluid dynamics**

Changes in intra-tendon fluid dynamics have been proposed as a possible mechanism of effect for the benefits of eccentric exercise.\textsuperscript{31,32} Several authors have demonstrated that eccentric exercise reduces tendon diameter (anterior to posterior thickness), and that this may be related to changes in intra-tendon fluid content.\textsuperscript{31,32,85} The results of Grigg et al's work suggests that the change in tendon thickness was less in subjects with tendinopathy compared to a healthy control group.\textsuperscript{32} Whether this response is beneficial or predictive of recovery has not been yet been established. However, other groups have shown that the Achilles tendon anterior to posterior (AP) diameter increases with eccentric exercises.\textsuperscript{89} The differing results may be related to the mode of assessment, US versus MRI, or issues with reliability of measurements. The findings of reduced volume are difficult to rationalize in the face of studies reporting immediate increases in tendon volume after loading, albeit in tendons other than the Achilles.\textsuperscript{89} Further studies need to address what substances (chemicals) are within the tendon and how they may be affected by short term and long term loading.

**NEUROMUSCULAR ALTERATIONS**

**Force fluctuations within the tendon**

Force fluctuations are alterations in tendon load occurring during muscle contractions. Many authors offer alternate names such as oscillations or vibrations but effectively they are describing a motor pattern variation that influences tendon load and thereby affects the tendon biochemically. These fluctuations seem to occur more frequently during eccentric than concentric muscle activities.\textsuperscript{35-39}

Rees et al\textsuperscript{38} and Henriksen et al\textsuperscript{87} showed altered neuromuscular forces during eccentric activity in healthy participants but Griggs et al also showed higher levels in patients with AT.\textsuperscript{39} Griggs and Rees both suggest that these fluctuations may increase stress on the tendon and lead to advantageous tissue changes,\textsuperscript{36} however the reverse may in fact be true, that is, rather than helping recovery motor control issues may lead to structural overload and ultimately tendinopathy. It is important to understand the stretch shortening cycle (SSC) when considering the force fluctuations. The SSC is defined as pre-activated muscle undergoing a lengthening (eccentric) contraction followed by a muscle shortening (concentric) contraction.\textsuperscript{91,92} The SSC is associated with tendon lengthening due to its elastic nature, which allows temporary energy storage prior to recoil. During the SSC Achilles tendon forces may reach 9000N (12.5 times bodyweight)\textsuperscript{93} and strain (percentage of tendon elongation) is reported as between 4.1-12.8\% levels,\textsuperscript{93-96} with tissue rupture reported at strains of 9.9\% in the only study on the human Achilles tendon.\textsuperscript{97} Repetitive SSC’s have been shown to lead to tissue failure and rupture of the Achilles with loads that are within in vivo limits.\textsuperscript{97} The reason that this may be possible is that muscle activation has been shown to increase tendon stiffness thereby increasing the force required to lengthen the tendon by a given amount effectively reducing tendon (elongation) strain.\textsuperscript{65} Studies assessing tendon strain to failure limits have not previously accounted for the muscles ability to affect tendon stiffness and have instead used passive testing protocols, this effectively makes many of the models used to assess tendon function/loading incorrect, which in turns limits the accuracy of the conclusions reached in many of the studies.

Force fluctuations are the result of non-optimal coordination of motor units\textsuperscript{36-39} and these fluctuations appear
to create “mini SSC’s” increasing the number of SSC’s the tendon is exposed to per loading phase. This phenomenon is likely to increase tendon load and initiate the cellular reaction associated with tendinopathy. There is currently no study that has investigated whether these force fluctuations are altered with eccentric (or other) rehabilitation techniques or whether these fluctuations are associated with other neuromuscular measures such as plantarflexor power.33,80,99

Muscle Power
Muscle power deficits have been identified in correlational studies assessing the plantarflexors.10,62,98,100-104 A prospective study98 clearly showed that torque below a 50Nm (Newton-meters) was predictive of AT development.98 Mahieu et al examined army recruits prior to their six-week basic training and tested their concentric strength using isokinetic dynamometry, and determined that a value below 50Nm was 85% sensitive for predicting AT development. Despite the link between muscle power and AT only Alfredson’s original paper has used power as an outcome measure and none of these studies have suggested why changes to muscle power may benefit patients with tendinopathy. Alfredson showed a significant loss of power (13.6-23.7% reduction) in the plantarflexors between limbs,10,100 which was resolved during rehab, but little consideration was given to how this may have influenced tendon pain.10 Whether the strengthening benefits from eccentrics somehow reduce tendon load or whether it simply changes DF ROM, as discussed earlier, thereby changing tendon load remains to be explored. These two possibilities need further investigation.

STRESS SHIELDING – A NEW PARADIGM
Plantarflexor muscle function has clearly been associated with AT and prospective studies have further supported this cause and effect relationship, but despite this the current literature has failed to offer any reason why muscle weakness may cause tendinopathy or why neuromuscular adaptions may lead to recovery from AT. This section discusses the role of the muscle in controlling tendon forces as a novel paradigm in tendinopathy treatment.

The SSC is one of the key principles associated with tendinopathy and is commonly described as a passive tendon only process,57 however studies clearly show that the muscle function is essential to the SSC.57,58,91,105 Work by Komi91 and Lindstedt et al57,58 has highlighted that the muscles also function as energy storage systems during the SSC by stiffening. This appears to be due to pre-activation and stretch reflex loops.91 This pre-activation is a neuromuscular rather than structural adaptation. The suggestion from this data is that muscle function, in addition to tendon characteristics, are essential for efficient functioning during the SSC. Further work has shown that muscle function increases tendon stiffness thereby improving its response to strain.33,65 This in itself may actually serve as protective mechanism for the tendon, as without muscle activity the tendon is less stiff, equating to a given load bringing about a larger length change in the tendon. Lengthening of a tendon without muscle activity appears to produce higher tendon strains, possibly achieving levels that may be detrimental to the tendon health.106,107 Lindstedt et al58,108 have studied MTU function during SSC contractions and they offer an alternative view to the commonly described model of tendons shielding muscles.109 Their suggestion is that muscles can function as shock-absorbers, during which the muscle absorbs energy as heat, or they can function as a time dependent spring and increase the elastic recoil potential, reducing energy requirements and heat production. This proposed time dependent spring function can potentially be modified by eccentric training through alterations in neuromuscular function, which may effectively improve the economy of simple SSC tasks like hopping. It appears that hopping frequency is internally controlled within individuals and relates to the frequency that is most energy efficient, there is a strong relationship between body mass and preferred frequency.110,111 Externally controlled changes to hopping frequency have been shown to increase oxygen demands, effectively showing reduced energy efficiency.58 Interestingly the work of Linstedt et al showed that eccentric training led to an 11% increase in internally controlled hopping frequency. The observation of increased hopping frequency shows an alteration to the spring function of the muscle, which matches predictions of reducing body mass by 50%.58 A more efficient spring function of the plantarflexors would increase elastic recoil and reduce absorption of energy (heat) in the Achilles tendon. Heat has been linked to tendinopathy with several studies showing heat shock proteins to be involved in tendinopathy models.112-115
The involvement of heat shock proteins suggests tendons heat up during activity; some authors have suggested this reaches levels associated with catabolic activities.\textsuperscript{116} This has been further evidenced in Equine tendons with temperature levels reaching as high as 45 degrees Celsius during exercise,\textsuperscript{117} a temperature of this level is damaging to tendon cells and is has been proposed as a potential key component of tendinopathy.\textsuperscript{114,116,117} Mathematical modelling of human tendons also predict the same temperature changes.\textsuperscript{117}

An alternative mechanism links to mechanical load on the tendon and the muscles ability to act as a shock-absorber. During eccentric movements muscles lengthen, towards the end of their range muscle lengthening ceases and the tendon undergoes a stretching period prior to a shortening – the SSC. This function allows the muscle to decelerate the movement prior to maximum tendon strain at terminal dorsiflexion. If the muscle is weak or poorly co-ordinated the muscle appears to undergo a stop: start eccentric type of contraction, identified by Rees et al as force fluctuations and Grigg et al as force frequency characteristics in the 8-12 hz range. This is demonstrated clinically by a physiological tremor or fasciculation. These stop: start contractions expose the tendon to more frequent SSC's during a given action. This un-coordinated eccentric contraction has been observed in healthy subjects\textsuperscript{36,37} and shown to be more frequent in AT.\textsuperscript{38,39} These neuromuscular co-ordination issues may expose the tendon to repeated SSC's during a single functional movement i.e. walking or running. The amplitude of tendon strain is not yet known during these fluctuations but it may be that either the amplitude or accumulative load is greater than in healthy subjects with normal

![Flow chart](linktosvg)

**Figure 1.** Flow chart depicting the potential role muscle co-ordination may have in tendinopathy. The MTU as a whole can function as a shock-absorber and absorb energy in the form of heat. Changes in muscle stiffness associated with eccentric training or good pre-existing function leads to less energy absorption and more recovery of energy through elastic recoil, this may protect the tendon by preventing excessive heat absorption/production.
CONCLUSION

Current literature regarding AT suggests that eccentric exercises are effective in the treatment of pain and the restoration of function. There are numerous potential explanations supporting the rationale for effectiveness of eccentric regimes, however many of the suggested explanations have not been fully investigated.

Of the potential mechanisms, changes in neuromuscular output appear to be the most promising but are currently poorly understood and under researched. The changes necessary for benefit may include increased MTU stiffness, increased strength, and shifts in the length tension curve. It is possible that these neuromuscular changes reduce the load on the tendon by "smoothing muscle contractions" (force fluctuations) and thereby reduce maximal or accumulative tendon strain. This may affect tendon homeostasis.

Future research should focus on neuromuscular alterations associated with AT and determine how treatment influences these parameters. Additionally, combining studies of neuromuscular parameters and alterations with investigations of intra-tendon fluid dynamics and bio-chemical interactions would provide a more in-depth understanding of the mechanisms involved. The proposed studies could focus on plantarflexor power (concentric and eccentric), force fluctuations during eccentric movements, shift(s) in the angle of peak torque, and any changes that may occur in the SSC. Further studies would need to determine how neuromuscular changes influence ground reaction force during functional tasks and relate these forces to tendon strain. This data may be important in prospective risk factor studies.

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ABSTRACT

Females participating in sports have the potential of developing one or multiple parts of the Female Athlete Triad, defined as the inter-relationship among energy availability, menstrual function, and bone mineral density. Energy availability, defined as dietary energy intake minus exercise energy expended, is believed to be at the cornerstone of the triad, and complications from low energy availability span many of the bodily systems and can have psychological implications. Treatment of the triad requires a comprehensive multi-disciplinary approach.

Physical therapists frequently treat injured athletes and may have prolonged interactions with athletes depending on the length of the rehabilitation process. In addition to examination, assessment, and treatment of injuries, the role of the physical therapist includes prevention, and the promotion of health, wellness, and fitness. Thus, the goal of this clinical commentary is to identify and describe essential knowledge for the physical therapist, clearly identify the role of the physical therapist as part of multi-disciplinary management team, and outline resources for the physical therapist and athletes relevant to the female athlete triad.

Level of Evidence: 5

Keywords: Bone health, energy availability, female athlete triad, menstrual status
INTRODUCTION
Participation in sports is typically associated with psychologic, sociologic, and physiologic health benefits. However, in females, a potential negative result can be the development of the Female Athlete Triad (the triad), defined as the inter-relationship among energy availability (EA), menstrual function, and bone mineral density (Figure 1). A recent systematic review reported the prevalence of all three components in female high school, collegiate, and elite athletes to be between 0% and 16%. The prevalence of two components was 3% to 27%, and the prevalence of any single component was 16% to 60%. Due to the interactive nature of the components of the triad, individuals with just one or two components of the triad are still at risk for health issues and may be at risk for developing all three components.

Physical therapists frequently treat injured athletes and may have prolonged interactions with athletes depending on the length of the rehabilitation process. Despite frequent treatment of female athletes, two surveys that assessed physical therapists' knowledge of the female athlete triad have yielded less than optimal results. Results of the survey by Troy et al. demonstrated that only 43% of physical therapists could identify all three components of the triad. Likewise, results of a study by Pantano demonstrated that 61% of therapists stated that they knew the three components of the triad, but only 21% could actually state all of them. Surprisingly, these therapists were all members of either the Orthopedic or Sports Sections of the American Physical Therapy Association and approximately one quarter of them identified that they had treated athletes in the past year with symptoms related to the triad. However, the lower percentage of therapists correctly identifying the triad as opposed to the aforementioned study by Troy et al may have been due to variances in the correct terms accepted. For example, disordered eating or low energy availability was accepted, but eating disorders was not. Nonetheless, only 59% reported being comfortable discussing disordered eating and menstrual dysfunction with their athletes.

The Guide to Physical Therapist Practice defines the role of the physical therapist include prevention and the promotion of health, wellness, and fitness, in addition to the typical role of rehabilitation of injuries. Prevention may be primary, preventing a condition in a target population; secondary, decreasing the duration or severity of disease; or tertiary, restoring function in a patient dealing with a chronic illness or disability. Primary prevention includes screening for disease(s), identifying areas for initiation of prevention strategies, and potential referral to other health care providers. With appropriate knowledge of the triad, the skills and background of the physical therapist are appropriate for each of these roles in prevention and health promotion. Thus, the goal of this clinical commentary is to identify and describe essential knowledge for the physical therapist as part of multi-disciplinary management team, and outline resources for the physical therapist and athletes relevant to the female athlete triad.

THE FEMALE ATHLETE TRIAD DEFINED
A multidisciplinary workgroup assembled by The American College of Sports Medicine (ACSM), described the female athlete triad as consisting of three inter-related conditions that each occur on a spectrum from normal function to dysfunction:
The importance of presenting the triad components as conditions that each occur across a spectrum is worth noting because this may allow providers to recognize that athletes may present with subclinical disorders that should be identified and treated before full-blown eating, menstrual, or bone disorders ensue.9

In the triad, low EA may occur with or without an eating disorder. EA is calculated by taking the dietary energy intake (in kilocalories) and subtracting the energy (in kilocalories) expended during exercise.10 The equation for EA is displayed below:

\[
\text{Dietary energy intake} - \text{Exercise energy expenditure} = \text{Energy Availability}
\]

The result, known as EA, is how much energy remains for other body functions. Low EA may be a result of an eating disorder or eating practices such as fasting or food avoidance that decrease energy intake. Alternatively, low EA can ensue either purposively or inadvertently without an eating disorder if an athlete’s energy demands exceed her caloric intake. Health may be impaired as the energy required for basic physiological functions of the body is not available. Consequences can be far reaching and may include, but are not limited to the following: diminished ability to recover from injury, inability to build or maintain bone mass, impaired menstrual function and infertility, and an increased risk of cardiovascular disease.10

The spectrum of menstrual function is the second aspect of the triad. Women over the age of 15 are expected to have normal menses that occurs every 28 ± 7 days.11 This is considered “normal menses” or eumenorrhea. Menstrual dysfunction incorporates a spectrum of disorders from oligomenorrhea (menstrual cycle greater than 35 days) to amenorrhea (the absence of menstruation for greater than three months).1 Amenorrhea after the onset of menses (menarche) is referred to as secondary amenorrhea. Primary amenorrhea refers to the delay of menarche until after the age of 15.1,11,12 Other reproductive irregularities may be present in female athletes, including anovulation and polycystic ovarian syndrome, both of which may occur in the presence of normal menses. These conditions are difficult to identify, require advanced medical diagnosis, and may lead to problems even though menses is present;9 therefore, the physical therapist should not assume all menstrual dysfunction to be related to the triad.

The third component of the triad is the spectrum of bone health. Low bone density in female athletes is defined by the ACSM as “a history of nutritional deficiencies, hypoestrogenism, stress fractures, and/or other secondary clinical risks for fracture together with a bone mineral density (BMD) Z-score between -1.0 and -2.0.”1 Osteoporosis is defined as BMD Z-score below -2.0.1 When dosed properly, physical activity and exercise has proven to offer positive benefits with regard to bone mass. In fact, many athletes typically display bone mineral density that is higher than the average non-athlete, when compared by age.9 Forty-eight percent of skeletal mass and 15% of adult height should be attained during adolescence, and peak bone mass is achieved by 20-25 years of age.13,14 Thus, bone loss or impaired bone development in female athletes is particularly concerning.

There is a strong interrelationship between the three components of the triad; however, low EA is frequently described as being the “cornerstone” of the three potentially interrelated disorders.1,15 Dysfunction of the menstrual/reproductive system and the skeletal system can be related either directly or indirectly to EA. Optimal EA supports bone health both by maintaining the metabolic and endocrine pathways for eumenorrhea, related to estrogen production. Amenorrhea resulting from energy deficiency (low EA) is known as functional hypothalamic amenorrhea in which the complex hypothalamic-pituitary-ovarian axis is impacted and estrogen levels are diminished, despite no anatomic cause.11 Furthermore, the lack of estrogen further impacts bone density as estrogen has a protective effect on bone by inhibiting the function of the osteoclasts whose role it is to break down bone.

The impact of the triad is not limited to menstrual function and bone health. Complications from low EA and the additional consequences can span many of the bodily systems and can have psychological implications.1 Low EA has specifically been linked to depression, low self-esteem, and anxiety disor-
Due to the potential systemic impact of the triad, it is the opinion of the authors that physical therapists should be able to identify the components of the triad and describe their impact on the health of the female athlete, screen for risk factors of the triad, and articulate the role of the physical therapist in a multi-disciplinary approach to prevention and treatment of the triad.

IDENTIFICATION OF INDIVIDUALS WITH THE TRIAD

Though the components of the female athlete triad may be easy to define and comprehend, it is often difficult to identify those who are dealing with one of the components or its effects. First and foremost, to screen, evaluate, diagnose, or treat an athlete, the athlete must be willing to partake in that process. Often, an athlete does not realize they have low EA, low bone density, or that their lack of menstruation is abnormal. It is the responsibility of healthcare professionals, such as physical therapists, to be able to educate athletes, parents, and coaches regarding the components of the triad so that they do not go unnoticed.

Acknowledging that the physical therapist should not serve as a physician, counselor, dietician, or psychologist, there are several important ways that the PT can assist in identification of the areas of the triad in active women and girls. First, during the history and systems review, general questions should be posed about menstrual status and history. Second, a history of multiple or repeated stress injury to bone should trigger the PT to consider the triad as a potential contributory factor. Several important questions are proposed by the Female Athlete Triad Coalition Consensus group, which can be found in Table 1. The Consensus group suggests that all high school and college athletes be screened. The physical therapist could easily incorporate these questions into an initial examination of a female patient or during a pre-season screening event for female athletes.

Low EA, the main component of the triad, is quite complex and identification of this condition requires an objective view of the athlete as a whole. Traditionally, disordered eating has been described as being more prevalent in aesthetic and weight dependent sports; however, contemporary literature supports the suggestion that many female athletes are susceptible to the triad, regardless of the particular sport in which they participate. Thus, athletes of all types of sports should be properly screened for having low EA due to disordered eating using validated tools. Several validated tools are available for screening, including the LEAF Questionnaire for all aspects of the triad, the Eating Disorders Inventory (EDI-3) and the EAT-26 for eating disorders. Screening can take place during pre-participation exams conducted by a multidisciplinary team or in an annual health exam with a primary care physician.

The presence of subclinical disordered eating often goes missed and untreated because these eating pat-

<table>
<thead>
<tr>
<th>Table 1. Female Athlete Triad Consensus Panel Screening Questions for use during Preparticipation Evaluation</th>
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</thead>
<tbody>
<tr>
<td>1. Have you ever had a menstrual period?</td>
</tr>
<tr>
<td>2. How old were you when you had your first menstrual period?</td>
</tr>
<tr>
<td>3. When was your most recent menstrual period?</td>
</tr>
<tr>
<td>4. How many periods have you had in the last 12 months?</td>
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<tr>
<td>5. Are you presently taking any female hormones (estrogen, progesterone, birth control pills)</td>
</tr>
<tr>
<td>6. Do you worry about your weight?</td>
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<tr>
<td>7. Are you trying or has anyone recommended that you gain or lose weight?</td>
</tr>
<tr>
<td>8. Are you on a special diet or do you avoid certain types of foods or food groups?</td>
</tr>
<tr>
<td>9. Have you ever had an eating disorder?</td>
</tr>
<tr>
<td>10. Have you ever had a stress fracture?</td>
</tr>
<tr>
<td>11. Have you ever been told you have low bone density (osteopenia or osteoporosis)?</td>
</tr>
</tbody>
</table>

terns can be obscure and a person frequently does not have all of the criteria to fit into established diagnoses such as bulimia nervosa or anorexia nervosa. However, if an athlete has any eating disorder tendencies, such as dietary food restriction, purging behaviors, or any altered eating habits, they are at risk for developing disordered eating. These tendencies, even without a true eating disorder, may create a state of low EA and impact bone density. Many athletes lack proper knowledge about nutrition and may not realize that they are not eating enough for the amount of energy they expend.

In summary, athletes that are identified to have a risk of nutritional deficiency by simple questions should have more objective data gathered than just a simple body mass index (BMI) calculation, as such a calculation is very general, and there is not an adequate definition of a BMI that predisposes an athlete to development of the triad. Athletes with concern about BMI or body composition should be referred to a registered sports dietitian, who is able to perform a comprehensive nutritional assessment including a detailed dietary log, and who will ultimately determine if the athlete has low EA. Such detailed assessment and determination of EA is beyond the scope of practice of the physical therapist. A comprehensive exam, provided by a physician, may be recommended and should include lab tests, including a complete blood count, and potentially EKG, at the discretion of the physician. It is important to note that if athletes have one component of the triad, they should be screened for the other two as well and this can be accomplished by the physical therapist with simple questions and injury history queries. Note that any alteration in an athlete’s menstrual cycle requires further testing by the physician as there are many potential causes not identifiable by the physical therapist, including but not limited to hypothalamic amenorrhea, polycystic ovarian syndrome, or pregnancy. Finally, it should be noted that, menstrual irregularities in the adolescent female are common, with 65% of girls demonstrating oligomenorrhea during their first year after menarche, making identification of true dysfunction even more difficult to detect.

Low bone density is the final component of the female athlete triad and is equally difficult to diagnose. If an athlete has a history of repetitive or multiple site stress fractures or has had altered eating habits for a total of six months, it is important that she obtains a bone scan with dual-energy X-ray absorptiometry (DEXA) in order to determine her actual bone density. For more information regarding guidelines for obtaining or facilitating a referral to a physician for a DEXA scan, please refer to Table 2. Most typically the DEXA scan is not ordered by the physical therapist, rather, by the medical provider on the health care team.

Overall, it is the opinion of the authors that identifying an individual with the triad, or any of its component parts, can be quite difficult because there are many complex and inter-related contributory factors that span multiple systems. All component parts of the triad are difficult to diagnose individually, and many athletes are unaware that they are undernourished, have bone density issues, or menstrual dysfunction. The physical therapist is not prepared to diagnose all aspects of the triad, rather, should have an index of suspicion that allows for proper referral if needed. It is important for all healthcare professionals to work as a team in educating, identifying, and treating athletes who are at risk for or have aspects of the triad.

**MANAGEMENT OF THE TRIAD**

Treatment of individuals presenting with one or more components of the triad is essential for re-establishing balance among systems and requires the collective skill of a cohesive, multi-disciplinary intervention team. This team may include a physician, registered dietitian, mental health expert, physical therapist or athletic trainer, and coach. It is important that all members of this team work together to manage athletes with the triad because of their extensive, and often unique knowledge of the components of or contributors to development of aspects of the triad. Additionally, care should be taken in discussions with the athlete, as the triad is a sensitive topic.

Treatment of the triad is a complex process that can include pharmacological and non-pharmacological methods. The ultimate goal of treatment involves re-establishing a menstrual cycle and enhancing bone mineral density primarily through a change in diet, exercise training, and increasing overall EA.
needed with younger, athletic populations.

Finally, the use of bisphosphonates or other bone restorative medications typically used with those with postmenopausal osteopenia or osteoporosis should be approached with great caution, and only under the direction of an endocrinologist or specialist in metabolic bone diseases, as there are no published studies of the use of these medications in active, athletic females with triad disorders. Thus, since pharmacological intervention is not optimal and caloric alterations leading to weight changes of as little as 10% weight reduction can result in a 1-2% loss of BMD, managing energy availability and proper nutritional intake is of utmost importance in dealing with the likely cause of both menstrual and bone dysfunction.

It should be noted that the PT could have a positive impact in both identification and management of stress injuries/stress fractures in the female athlete, by assessing and managing training changes, biomechanical support, or equipment changes. This type of bony injury, especially when repetitive, could be an indication of bone density issues or biomechanical stresses that cause bony tissue to fail. In the presence of multiple site or repeated stress fractures, the PT could ask simple questions related to nutritional and education, modification of unhealthy behaviors such as dietary restriction and overtraining, and addressing biomechanical factors that may contribute to bone stress.

The first step in treating low EA includes meeting with a sports nutritionist and possibly a behavioral health specialist, as most physical therapists do not possess the ability to perform in-depth nutritional counseling. Maintaining optimal energy may be accomplished by either decreasing energy expenditure or increasing energy input. Diet quality also is an issue as this may directly related to bone health; calcium and Vitamin D intake must be adequate.

With regard to treatment of bone density issues, medical and hormonal management may be a typical first line intervention. However, pharmacologic therapy has had a record of limited success in actually treating and resolving the dysfunctional triad components. Oral contraceptives are sometimes prescribed to restore menstruation; however, the impact of these medications on restoring bone density is not conclusive. Currently, some have suggested the use of transdermal estrogen to increase a female athlete's circulating estrogen, but further studies regarding the efficacy of such interventions are needed with younger, athletic populations. Finally, the use of bisphosphonates or other bone restorative medications typically used with those with postmenopausal osteopenia or osteoporosis should be approached with great caution, and only under the direction of an endocrinologist or specialist in metabolic bone diseases, as there are no published studies of the use of these medications in active, athletic females with triad disorders. Thus, since pharmacological intervention is not optimal and caloric alterations leading to weight changes of as little as 10% weight reduction can result in a 1-2% loss of BMD, managing energy availability and proper nutritional intake is of utmost importance in dealing with the likely cause of both menstrual and bone dysfunction.

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tion and energy availability, which may illuminate potential nutritional contributions to the triad and prompt more in depth screening.

Although treatment of the triad may seem simple, it is actually quite complex. Psychological pressures may need to be addressed and are not easy to overcome; even if disordered eating is identified, it may be hard to correct, and the many characteristics of an excellent athlete including passion, dedication, and drive may be difficult to reign in to prevent overtraining. Thus, prevention and early recognition of the triad is of utmost importance to ensure timely intervention.

Although beyond the scope of this clinical commentary, experts in the field have provided a consensus statement regarding treatment and return to play of the female athlete with the triad. This is an important and relevant document for the physical therapist who works with female athletes.

**PREVENTION STRATEGIES**

Perhaps the most important aspect for the physical therapist dealing with the triad is preventing it from occurring in the first place. Education is the key piece to preventing the female athlete triad. Athletes, as well as their coaches and caregivers and the entire healthcare team, should be informed of the components of the triad and of ways to detect triad-associated signs and symptoms. In a study by Troy et al, only 48% of physicians and 8% of coaches could identify all three components of the triad. Resources for the athlete, caregivers, and the healthcare team are outlined in Table 3.

With regard toward prevention of low EA, nutrition education for athletes, coaches and parents is paramount. Nutrition education should include information on nutrient dense foods, hands-on practice in selecting foods, and dietary habits for long-term health as well as the caloric demands of sport and training at high levels. This education may be a part of physical therapist practice at a basic level, but may be delivered in greater depth by a registered dietician.

Along with nutrition education is the need for honest discourse regarding sports health and weight. Many athletes believe that “thinner is better” and “every sport has an ideal body weight.” There is not an optimal value when it comes to body weight, and as previously discussed, low body weight or low EA may result in immediate performance difficulties or long-term health problems. Furthermore, many people believe that amenorrhea is a normal occurrence in highly trained athletes, but that is not the case. Amenorrhea is not normal in athletic women (after the onset of menses), and has a negative affect that can decrease sports performance, be related to injury, and delay the injury healing process.

Athletes Targeting Health Exercise and Nutrition Alternatives (ATHENA), has been developed to educate high school female athletes on self-esteem, societal pressure, healthy norms, and sports nutrition. This program has long-term benefits including decreased diet pill use, participants being informed of calcium requirements, and being able to select a heavier body weight image as “healthy” than the control group. Programs such as these that are multifaceted and include a psychosocial aspect may be important in educating young athletes.

With regard to prevention of bone density issues, the topics of diet and adequate macro and micronutrients are highly relevant. Adequate calcium in the presence of Vitamin D is necessary for adequate bone banking in the adolescent years, as well as bone density maintenance throughout adulthood. Additionally, gradual increases in training stimulus, and the importance of adequate rest during training is highly relevant for the physical therapist to address during education. Biomechanical dysfunction or alterations could be identified in screening, including foot type (pes planus or pes cavus), jumping and landing abilities, and core/hip muscle strength and neuromuscular control. These facets may contribute

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**Table 3. Female Athlete Triad Resources for Health Professionals, Athletes, Parents, and Coaches**

- [http://femaleathletetriad.org/](http://femaleathletetriad.org/)
- [http://www.thinkersplay.org/triad-talk/](http://www.thinkersplay.org/triad-talk/)
- [http://www.moveforwarddoc.com/symptomsconditionsdetail.aspx?cId=0ca4b72e-6d1d-4b90-b1ec-8d8b8c3069e8-7a5f0abA](http://www.moveforwarddoc.com/symptomsconditionsdetail.aspx?cId=0ca4b72e-6d1d-4b90-b1ec-8d8b8c3069e8-7a5f0abA)
- [http://www.sportsnutritionalsociety.org/find-a-nutritionist.html](http://www.sportsnutritionalsociety.org/find-a-nutritionist.html)
- [http://www.allianceforeatingdisorders.com/portal/dsm-anorexia#WY2OUGC1ds](http://www.allianceforeatingdisorders.com/portal/dsm-anorexia#WY2OUGC1ds)
to abnormal bone or joint stresses, leading to stress reaction/fractures, overuse injuries.

Clearly, pre-season or primary prevention strategies are highly relevant for the prevention of the triad. The physical therapist should be involved in general nutritional screening, screening for movement dysfunction, and simple menstrual screening questions that could identify aspects of the triad. Additionally, during an initial evaluation of a female athlete, simple history and systems review questions could illuminate aspects that may be of concern in female patients who may be at risk for development of the triad.

CLINICAL IMPLICATIONS FOR THE PHYSICAL THERAPIST

Physical therapists can and should be involved by participating in, or holding pre-participation screens for athletes before their season starts. This can help with identifying those at risk of the female athlete triad before it becomes their reality. Physical therapists can play a role in providing referral sources for patients and their families to the proper people to talk to about nutrition, oral contraceptive use, stress fracture assessment, and menstrual dysfunction, which all play a role not only identification but treatment of the triad.6

Physical therapists should be readily involved in widespread educational endeavors including delivering lectures and presentations pre-season, or during sports seasons, related to proper training, providing nutritional resources, and clinical signs and behaviors of the female athlete triad.1,6,9

In educational settings either with groups or individual patients and clients, it is very important that the physical therapist be ready and able to discuss and clarify the following “myths” associated with the Female Athlete Triad:

1. Myth: It is OK to not menstruate.
   Reality: If a female athlete has not had a period for 3 months or more, she needs to be seen by a physician.1,12

2. Myth: Thinner is better for performance; “the less I weigh the better I perform.”
   Reality: Being under your ideal body weight likely means that you have lost muscle mass and may not perform to your optimal abilities. A strong body is best prepared for optimal performance.29

3. Myth: It is acceptable to follow a low carbohydrate diet or exclude foods as an athlete.
   Reality: Low carbohydrate diets are not appropriate for an athlete, and will likely result in low energy availability. Also, avoiding certain food groups such as dairy products and rich sources of iron (e.g. red meat) may affect your bone health and training abilities.29

4. Myth: Multiple stress fractures are typical when training.
   Reality: This is likely your bones ineffectively dealing with stress placed on them, and may be an indication of dietary or training errors. Impairment of bone remodeling is considered to be the origin of low BMD in adolescent athletes,12 which may contribute to the prevalence of stress reactions and stress fractures.

CONCLUSION

The female athlete has unique physiological, endocrine, and psychological traits. These traits and demands place her at risk for development of the female athlete triad. All physical therapists should be able to identify the component parts of the triad, be prepared to screen female athletes for these components, and have pre-identified strategies for referral and management if appropriate. Energy availability appears to be paramount in the management strategies for all aspects of the triad; therefore, the physical therapist must be able to identify whether or not the female athlete is meeting key energy-related requirements or refer to other health care providers as appropriate. An important potential role for the physical therapist is education about the triad to athletes, their parents, coaches, and the medical community at large. The female athlete triad is an important prevention and wellness concept that all physical therapists should be able to address.

REFERENCES


CORRIGENDUM

PASSIVE HIP RANGE OF MOTION IS REDUCED IN ACTIVE SUBJECTS WITH CHRONIC LOW BACK PAIN COMPARED TO CONTROLS, Volume 10, Number 1, February 2015, Pages 13-20.

The paper “Passive Hip Range of Motion is Reduced in Active Subjects With Chronic Low Back Pain Compared to Controls” was originally published in IJSPT in February 2015, with an incorrect name for one author. Please note: Dr. Jun G. San Juan, PhD, ATC was incorrectly listed as Juan, JG and should have been San Juan, JG.
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