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ABSTRACT

Background: Plantar fasciitis (PF) is the most common cause of heel pain that affects 10% of the general population, whether living an athletic or sedentary lifestyle. The most frequent mechanism of injury is an inflammatory response that is caused by repetitive micro trauma. Many techniques are available to diagnose PF, including the use of ultrasonography (US).

Purpose: The purpose of this study is to systematically review and appraise previously published articles published between the years 2000 and 2015 that evaluated the effectiveness of using US in the process of diagnosing PF, as compared to alternative diagnostic methods.

Methods: A total of eight databases were searched to systematically review scholarly (peer reviewed) diagnostic and intervention articles pertaining to the ability of US to diagnose PF.

Results: Using specific key words the preliminary search yielded 264 articles, 10 of which were deemed relevant for inclusion in the study. Two raters independently scored each article using the 15 point modified QUADAS scale.

Discussion: Six studies compared the diagnostic efficacy of US to another diagnostic technique to diagnose PF, and four studies focused on comparing baseline assessment of plantar fascia before subsequent intervention. The most notable US outcomes measured were plantar fascia thickness, enthesopathy, and hypoechogenicity.

Conclusion: US was found to be accurate and reliable compared to alternative reference standards like MRI in the diagnosis of PF. The general advantages of US (e.g. cost efficient, ease of administration, non-invasive, limited contraindications) make it a superior diagnostic modality in the diagnosis of PF. US should be considered in rehabilitation clinics to effectively diagnose PF and to accurately monitor improvement in the disease process following rehabilitation interventions.

Level of Evidence: 1A

Keywords: plantar fascia, plantar fasciitis, ultrasound

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INTRODUCTION

Plantar Fasciitis (PF) is the most common cause of heel pain, affecting 10% of the world’s general population, and over two million Americans each year.\(^1\) It is estimated that management of PF yields an estimated annual cost of $192-376 million, adding a preventable strain to the overall costs of health care.\(^2\)

The dysfunction and etiology of the PF is multifactorial, but most commonly it is a result of microtrauma (microtears) due to repetitive overload placed on the connective tissue in the plantar region. Over time, the microtears create structural fatigue and weakening of the connective tissue, leading to an inflammatory response, pain and discomfort. PF presents in both men and women in a relatively equivalent ratio, as well as in both athletic populations and individuals who live a more sedentary lifestyle.\(^1,3\) Although it is more commonly seen in individuals between the ages of 40-70 years, anyone may be predisposed to develop PF due to a variety of factors including: a recent increase in running or prolonged standing activities, pes planus or pes cavus foot types, excessive tibial torsion, tightness of the gastrocnemius, obesity, and the use of improper footwear that is being unsupportive or alters foot kinematics.\(^4,5,6,7,8\)

As diagnostic clinicians, physical therapists should use a variety of diagnostic tools in order to accurately diagnose PF, rule out differential diagnoses, and avoid implementing ineffective therapeutic interventions.\(^1\) A patient history that includes an increase in physical activities, pain that is throbbing or burning, pain during toe walking, ambulating without proper footwear, and initial pain in the medial heel region, noticeable after a prolonged period of inactivity (such as upon waking up in the morning), may be indicative of PF.\(^1,8,9\)

A clinical examination can provide valuable information to a physical therapist in order to efficiently diagnose PF. However, diagnostic imaging has been proven to be useful for further assessment of the plantar fascia structure that aids in the differential diagnosis.\(^1\) The imaging techniques that are available are US, magnetic resonance imaging (MRI), bone scintigraphy (BS), plain radiographs, and elastography. Radiographic images have been used in cases where calcaneal bone spurs are suspected to be present. However, subcalcaneal spurs may be present in individuals with and without PF, therefore have been acknowledged to not have a direct relationship to a diagnosis of PF.\(^1\)

Magnetic resonance imaging (MRI) has been confirmed as a reliable and validated tool to effectively diagnose PF.\(^10\) MRI’s are being used to assess and differentiate any abnormalities in the thickness of the plantar fascia. MRI, however, may be costly and time consuming and may have many precautions and contraindications that accompany the test, thereby eliminating its availability to a large population.\(^1\) Additionally, MR elastography utilizes same concepts of MRI and is able to visually display an image that explains the amount of stiffness in various soft tissue structures being examined.\(^11\) Bone scintigraphy (BS) has the capacity to demonstrate an abnormal uptake of radioactive material that has collected in the bone due to a current inflammatory response.\(^12\) Therefore, BS can be beneficial to see areas of abnormal bone growth and may be considered if symptomatic calcaneal heel spurs are suspected.\(^13,10\)

Since the 1940’s US has proven to be an excellent tool to assess musculoskeletal pathologies through the production of high quality spatial resolution sonograms, especially at the body’s more superficial structures and in areas of hypoechoogenicity.\(^14,1\) Hypoechoogenic areas exist where focal inflammation and diffuse tissue changes are present, thus resulting in a decreased transmission of sound waves back to the transducer head.\(^15\) Compared to other validated and reliable tests that are capable of visually inspecting soft tissue pathology, US offers a much more cost efficient test, easier administration, a faster process to achieve the results, a non-invasive approach, better patient tolerance, and enhanced ability to display enthesopathy associated with inflammation.\(^1,16\) Enthesopathy is visible on sonographic images at sites of muscular or tendon attachment where complete or partial ruptures may be present.\(^5\) US images allow for assessment of plantar fascia echogenicity, thickness, complete or partial ruptures, as well as the formation of bony spurs, intrafascial calcification, perifascial fluid collection, and fascial biconvexity.\(^5\)

The use of US is slowly becoming a more integral element of physical therapy practice, allowing for
a higher standard and overall quality of care to be delivered the patient. With the use of Diagnostic US, rehabilitation professionals including physical therapists can be more precise, and cost efficient with the diagnosis and treatment of PF. Adapting to advancements in the physical therapy profession allows therapists to optimize evidence based practice in diagnostic imaging in order to improve the human experience to its full potential. For additional information about the history of diagnostic imaging use by physical therapists and the legislative and regulatory background, the reader is encouraged to read the imaging education manual for doctor of physical therapy professional degree program that is published online through the imaging special interest group of the Orthopedic Section of the American Physical Therapy Association (APTA).

The purpose of this study is to systematically review and appraise previously published articles that evaluate the effectiveness of using diagnostic US in the process of diagnosing PF, compared to alternative diagnostic methods.

METHODS
Scholarly (peer-reviewed) diagnostic and intervention articles pertaining to the ability of US to diagnose PF published between 2000-2015 were systematically reviewed. The following databases were utilized in the search process: Medline, PubMed, CINHAL, Science Direct, Cochrane, Ovid, Sports Discuss and BioMed Central. Included articles must have been comparing US to another reference standard for diagnosing PF. Intervention studies were included if baseline assessments incorporated comparison using ultrasound to a second diagnostic method.

Two independently blinded raters performed database searches and screening of titles and abstracts, and all disagreements in their findings were resolved by a third independent rater. Results of the preliminary search revealed two hundred sixty four articles using these key words: “Plantar Fasciitis & Ultrasoundography”, “Plantar Fasciitis & ultrasound”, “Plantar Fasciitis & MRI (Magnetic resonance imaging)”, “Plantar Fascia & diagnostic imaging” and “Plantar Fasciitis & imaging”. Two hundred fifty three articles were excluded, and eleven articles were deemed relevant for continuation with full text evaluation. Each of the eleven articles was assigned a quality assessment score using the 15 point modified QUADAS from two independent blinded reviewers. A third reviewer was utilized if there were discrepancies on any of the 15 points, or the discrepancies had to be solved by raters’ consensus. One last article was discarded after full text evaluation. Finally, relevant data from each of the eleven articles was then summarized into a summary table.

To assess the quality of reviewed articles, researchers used a 15 point modified QUADAS scale. The scale was adapted from table 9.1 & 9.2 in chapter 9 of the Cochrane Handbook for Systematic Reviews of Diagnostic Test Accuracy Version 1.0.0. Data was extracted from each article and a summary of significant information from each article was presented in a table format. The following tables summarize the results of the reviewed articles (Table 1) and color coding indicates the extent of evidence found in each of the reviewed articles according to the modified QUADAS scale (Table 2).

DISCUSSION
The purpose of this study was to systematically review and appraise previously published articles between the years of 2000 and 2015 that evaluate the effectiveness of using US to diagnose PF as compared with alternative diagnostic methods. Such methods ranged from clinical examination to diagnostic imaging techniques. Although there were many methodological differences among the studies, some common tendencies were revealed within the studies.

Eight out of the ten included articles were identified as either randomized controlled trials or prospective comparative studies. The age range of the participants spanned from 42 years old to 58 years old with a mean age of 50 years. A majority of the articles (9/10) included greater female representation than male, with a total of 97 males and 186 females, collectively. Another prominent trend found throughout the articles, was that the participants were generally representative of an overweight to obese population, with a BMI ranging from 25.4 ± 3.2 to 31.4 ± 5.5.

Patient positioning during imaging was consistent between articles, with the most commonly docu-
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<th>Sample Characteristics</th>
<th>Study Design</th>
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<th>Outcome Measures</th>
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<td>Sabir et al. (2005)</td>
<td>14</td>
<td>77 symptomatic participants</td>
<td>Prospective study</td>
<td>To test the utility of sonography in the evaluation of plantar fascitis using the MRI as a reference standard.</td>
<td>Ultrasound: Subjects lay prone with their feet hanging off the examination table and the ankle dorsiflexed to 90°. Sagittal imaging of the plantar fascia.</td>
<td>Ultrasound successfully identified the following facial pathologies: Enthesopathy: In 28.9% of the sample Musculoaponeuropathies: In 7.5% of the sample, and rupture in 1.3% of the sample</td>
<td>Sonography is a promising and efficient tool in the diagnosis of plantar fasciitis and offers additional benefits over MRI, such as being cost effective.</td>
</tr>
<tr>
<td>Kapoor et al. (2010)</td>
<td>14</td>
<td>25 Participants</td>
<td>Prospective study</td>
<td>To evaluate the role of elastography in evaluating plantar fasciitis compared with diagnostic ultrasound and MRI.</td>
<td>Images were obtained in the longitudinal plane parallel to the plantar fascia by linear transducer.</td>
<td>Findings were graded into three grades: Grade I: Focal increased signal intensity of plantar fascia. Grade II: Increased signal intensity with changes involving more than 50% of the origin of the fascia. Grade III: Increased thickness of more than 4 mm</td>
<td>The combination of elastography with ultrasound improves the accuracy of diagnosing plantar fasciitis with results being comparable to MRI.</td>
</tr>
<tr>
<td>McMillan et al. (2012)</td>
<td>13</td>
<td>82 Participants</td>
<td>Randomized control trial</td>
<td>To investigate the effectiveness of ultrasound guided corticosteroid injection in the treatment of plantar fasciitis.</td>
<td>Images were obtained where the fascia crosses the anterior aspect of the inferior calcaneal border</td>
<td>Clinical examination, history, VAS, and Palpation. The experimental group had a mean plantar fascia thickness of 6.67 ± 1.53.</td>
<td>At baseline evaluation of the sample, ultrasonography successfully diagnosed all patients with plantar fasciitis.</td>
</tr>
<tr>
<td>Groshar et al. (2000)</td>
<td>13</td>
<td>43 Participants</td>
<td>Randomized controlled trial</td>
<td>To evaluate the accuracy of bone scintigraphy and diagnostic ultrasound in evaluating and diagnosing plantar fasciitis.</td>
<td>Ultrasound: Transducer aligned longitudinally with the plantar fascia. Patient is lying prone with the feet hanging off of the examination table.</td>
<td>PF Thickness: Symptomatic feet: 5.3mm±1.7mm Asymptomatic: 3.6mm±1.5mm Positive predictive value: greater than 3.9mm=84.3% Also, 70.7% symptomatic heels were positive for hypochoegeness.</td>
<td>Ultrasonography and bone scintigraphy are imaging modalities that both can be utilized in the successful diagnosis of plantar fasciitis in cases in which objective measures are required.</td>
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Table 1. Summary table characteristics of included articles (continued)

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<th>Study Type</th>
<th>Methodology</th>
<th>Ultrasound Description</th>
<th>PF Thickness</th>
<th>Bone Scintigraphy</th>
<th>Conclusion</th>
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<td>Yucel et al. (2009)</td>
<td>12</td>
<td>27 Participants</td>
<td>5 Male 22 Female</td>
<td>Mean Age: 45.8±12.0</td>
<td>Prospective study</td>
<td>To compare the efficiencies of; ultrasound, palpation and scintigraphy guided injections in the treatment of plantar fasciitis.</td>
<td>Ultrasound, scintigraphy, and palpation guided injections</td>
<td>PF Thickness: Ultrasound: 4.2±1.1mm Scintigraphy: Abnormal increased uptake in 68.6% Fat Pad Thickness: Ultrasound: 6.9±1.3mm</td>
<td>Ultrasound and bone scintigraphy are effective diagnostic tools for diagnosis of plantar fasciitis.</td>
</tr>
<tr>
<td>Chen et al. (2013)</td>
<td>12</td>
<td>38 Participants</td>
<td>Symptomatic: BMI 25.4±3.2</td>
<td></td>
<td>Cross-sectional observational study</td>
<td>To assess the accuracy of ultrasonography in diagnosing patients with chronic plantar fasciitis compared with a clinical examination</td>
<td>Ultrasound: Was used to capture grayscale and power Doppler images</td>
<td>PF Thickness: Patient Group: Average of 5.0mm thick Control Group: Average of 3.3mm thick The foot function index has a positive relationship with the thickness of the plantar fascia.</td>
<td>Ultrasongraphy was found to be a successful tool in diagnosing pathology and detecting changes in the plantar fascia. The vasculature of the plantar fascia can be correlated to the development of plantar fasciitis.</td>
</tr>
<tr>
<td>Kane et al. (2001)</td>
<td>11</td>
<td>23 Participants</td>
<td>9 Male 14 Female</td>
<td>Mean Age: 58±2.19</td>
<td>Randomized controlled trial</td>
<td>To compare ultrasonography with bone scintigraphy in the diagnosis of plantar fasciitis.</td>
<td>Ultrasound: Plantar fascia thickness measured on the longitudinal view of heel and confirmed on a transverse view.</td>
<td>PF Thickness: Ultrasonography: Mean: 5.7±0.03mm in symptomatic heels 3.8±0.2mm in asymptomatic heels.</td>
<td>Ultrasonography and bone scintigraphy were confirmed to be sensitive and specific tests for diagnosing plantar fasciitis.</td>
</tr>
<tr>
<td>Fabrikant &amp; Park (2011)</td>
<td>11</td>
<td>63 Participants</td>
<td>Experimental: 14 Male 16 Female</td>
<td></td>
<td>Prospective study</td>
<td>To compare the baseline plantar fascia thickness between a control group and a study to the faces pain rating scale.</td>
<td>Longitudinal sonograms Patient sitting with feet over edge of the table in slight plantar flexion PF thickness measured from the base of the medial calcaneal tubercle.</td>
<td>Experimental Group: PF thickness: 0.633 ± 0.115 R Control Group: PF thickness: 0.325 ± 0.047 R</td>
<td>Office based ultrasonography can help diagnose and confirm plantar fasciitis as a non-invasive, cost effective, and radiation-free diagnostic modality.</td>
</tr>
<tr>
<td>Chueh-Hung Wu et al. (2012)</td>
<td>10</td>
<td>1 Female participant</td>
<td>Age 30</td>
<td></td>
<td>Case-study</td>
<td>To investigate the accuracy of diagnostic sonoelastography in the diagnosis of plantar fasciitis compared with traditional B-Mode ultrasonography.</td>
<td>Sonoelastography was performed four weeks after a traditional B-Mode ultrasound in order to diagnose plantar fasciitis.</td>
<td>PF Thickness: Traditional B-Mode: 2.8mm Sonoelastography: Indicated plantar fascia was softer and weaker on the symptomatic foot</td>
<td>Sonoelastography was more successful than traditional B-Mode ultrasound in the diagnosis of plantar fasciitis that was confirmed clinically.</td>
</tr>
</tbody>
</table>
mented position being prone with the feet hanging off of the examination table. The foot was positioned in neutral to slight dorsiflexion, diagnosing pathologies of the plantar fascia utilizing longitudinal and transverse. Multiple transducer frequencies were reported, ranging from 4-13MHZ.

Included studies consistently used a variety of similar diagnostic tools to assess and diagnose PF. Studies compared US with MRI, bone scintigraphy, elastography, and clinical examination to accurately and effectively diagnose PF. All bone scintigraphy measurements were able to visually evaluate only increased uptake in regions of increased metabolic activity. MRI based elastographic assessment was present in two out of the ten articles and was used to measure the thickness, echogenicity, stiffness, and intrafascial changes of the plantar fascia.11,21 Significant diagnostic factors commonly referenced throughout the articles which were used as diagnostic criteria that may not have been represented by imaging modalities included the patient’s apprehension of pain, the heel tenderness index (HTI), visual analog scale for pain, vascularity index (VI) and the foot function index (FFI).

During ultrasonographic assessment of the plantar fascia, the most common outcome measure utilized was the plantar fascia thickness (at site of calcaneal insertion), utilized in nine out of the total 10 articles.4,14,21,13,19,11,10,12 Plantar fascia thickness as measured by ultrasound ranged from 4.2 ± 1.1 mm to 6.67 ± 1.53 mm for all study groups, using any thickness above 4.0 mm as a positive result. Other prevalent features assessed by the US were echogenicity, presence of bony spurs, presence of perifascial fluid, bioconvexity of the plantar fascia at its origin compared to middle and distal thirds, and vascularity of the plantar fascia.11,21 MRI similarly assessed thickness of the fascia, as well as enthesopathy associated with ligamentous rupture.4,11,20

Comparison with MRI
Three studies directly compared US to magnetic resonance imaging (MRI).4,11,20 MRI, was used as the reference standard in two studies.11,20 Sabir et al20 reported sensitivity and specificity for US diagnosis of PF of 80.9% and 85.7%, respectively, when compared to MRI. Kapoor et al11 reported slightly lower numbers for the sensitivity and specificity of 65% and 75%, respectively, also when compared to MRI. Two studies compared elastography to US,11,21 three studies compared scintigraphy to US,13,19,12 while four other authors used a clinical examination as the reference standard against US (please refer to the summary table). Common clinical examination data included; a history of inferior heel pain, first step pain, and calcaneal tenderness.

Comparison to Elastography
The use of elastography, which has a similar imaging process and results as US (however; more expensive

### Table 1. Summary table characteristics of included articles (continued)

| Abdel-Wahab et al. (2008) | 10 | 17 Participants 9 Male 8 Female Mean Age: 42.47 ± 7.63 | Prospective study | To compare high-resolution ultrasound to MRI in confirming a clinical diagnosis of plantar fasciitis. | Longitudinal sonograms Prone position, with the patient’s feet dorsiflexed Sagittal scans performed with heels in a slight medial inclination toward the attachment of the plantar fascia | Experimental Group: Plantar fascia thickness: Ultrasound: Mean: 4.9 ±0.13 MRI: Mean: 5.14 ± 0.13 | The diagnostic accuracy of ultrasonography is comparable to that of MRI in the clinical diagnosis of plantar fasciitis and it could be the straightforward initial imaging modality to confirm clinically suspected plantar fasciitis. |
Table 2. Color Coded Modified 14 Point QUADAS Scores for the included articles. Adapted From Reitsma et al., The Cochrane Collaboration

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<td>1- Was the spectrum of patients’ representative of the patients who will receive this test in practice? (representative spectrum)</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
</tr>
<tr>
<td>2- Is the reference standard likely to classify the target condition correctly? (acceptable reference standard)</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
</tr>
<tr>
<td>3- Is the time period between reference standard and index test short enough to be reasonably sure that the target condition did not change between the two tests? (acceptable delay between tests)</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
</tr>
<tr>
<td>4- Did the whole sample or a random selection of the sample, receive verification using the intended reference standard? (partial verification avoided)</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
</tr>
<tr>
<td>5- Did the patients receive the same reference standard irrespective of the index test result? (differential verification avoided)</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
</tr>
<tr>
<td>6- Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)? (incorporation avoided)</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
</tr>
<tr>
<td>7- Were the references standard results interpreted without knowledge of the results of the index test? (index test results blinded)</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
</tr>
<tr>
<td>8- Were the index test results interpreted without knowledge of the results of the reference standard? (reference standard results blinded)</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
</tr>
<tr>
<td>9- Were the same clinical data available when test results were interpreted as would be available when the test is used in practice? (relevant clinical information)</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
</tr>
</tbody>
</table>
and not as readily available), may have an advantage over US because it is able to depict early changes in tissue stiffness resulting from micro-trauma. These intrafascial changes are present before inflammation and swelling of the perifascial structure are able to be seen on US, leading to elastography having a significantly higher sensitivity and specificity (98% and 83.3% respectively) for diagnosing PF in the early stages, and with the progression of PF, the diagnostic value of elastography further increases to an accuracy of 96%. In some cases, obvious morphologic changes may never become present in symptomatic heels, so US may not be able to depict changes in the plantar fascia thickness, whereas Elastography may be able to detect intrafascial changes in the structure which helps the early diagnosis of PF.

Four out of the total ten articles reviewed were intervention articles that assessed changes in plantar fascia thickness in response to administration of treatment. Before treatment was given, the intervention articles used baseline assessments to compare US to other diagnostic criteria. Two of the four intervention articles compared US to bone scintigraphy, while the other two compared ultrasonographic assessment to clinical examination data and a pain rating scale. Pain rating scales correlated directly with increased thickness in plantar fascia at the calcaneal attachment site as revealed on US. Secondarily, increased thickness and higher pain ratings correspondingly correlated with increased uptake of radioactive material as seen on bone scintigraphy.

The results of the reviewed studies indicate a high level of agreement between the diagnostic capabilities of US to MRI, elastogrpahy, bone scintigraphy, and clinical examination. US has proven to be an effective and efficient diagnostic tool in the diagnosis of PF; however, not more effective than MRI or elastography according to the reviewed studies.

**Limitations and directions for future research**

This systematic review was limited by the number of diagnostic studies found that met inclusion/exclusion criteria. Due to this fact, four intervention articles were included in the review that did not provide sensitivity and specificity values. Due to this limitation, the reviewed articles were not homogenous.

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**Table 2. Color Coded Modified 14 Point QUADAS Scores for the included articles. Adapted From Reitsma et al., The Cochrane Collaboration (continued)**

<table>
<thead>
<tr>
<th>10- Were uninterpretable/intermediate test results reported? (uninterpretable results reported)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11- Were withdrawals from the study explained? (withdrawal explained)</td>
</tr>
<tr>
<td>12- Did the study provide a clear definition of what was considered to be a ‘positive’ result?</td>
</tr>
<tr>
<td>13- Had test operators had appropriate training?</td>
</tr>
<tr>
<td>14- Was the treatment withheld until both the index test and reference standard were performed?</td>
</tr>
<tr>
<td>15- Was the study free of commercial funding?</td>
</tr>
<tr>
<td>Final QUADAS Score</td>
</tr>
</tbody>
</table>

| 10 | 10 | 11 | 11 | 12 | 12 | 13 | 13 | 14 | 14 |

| 80% | 93% | 93% | 87% | 100% | 100% |
enough to complete a comprehensive quantitative analysis or meta-analysis.

**CONCLUSION**

US should be considered early in the process of diagnosing PF. Compared to other imaging modalities, US is cost-effective, non-invasive, safe, portable, radiation-free, becoming available and easily administered. A unique feature of US is the ability to scan dynamic structures within the body (like contracting muscle and moving tendons), which is not possible in some other forms of imaging. The ability of US to accurately diagnose PF and further assess improvements throughout the plan of care makes it a valuable tool to enhance physical therapist practice. The future direction of the practice of physical therapy is to have a diagnostic ultrasound machine in every clinic, as well as the proper training to operate the machine and interpret the results. The common use of US will help to improve the degree of objectivity behind soft tissue clinical diagnoses that are made, thus improving the ability of a therapist to appropriately administer physical therapy interventions.

**REFERENCES**

ABSTRACT

**Background:** Recently, dry needling has emerged as a popular treatment for muscular pain and impairments. While there are numerous studies detailing the benefits of dry needling for pain, few studies exist examining the effects on soft tissue mobility.

**Purpose:** The purpose of this study was to determine if the addition of hamstring dry needling to a standard stretching program results in greater improvements in hamstring flexibility compared to sham dry needling and stretching in subjects with atraumatic knee pain. Additionally, squat range of motion, knee pain, and the Lower Extremity Functional Scale were compared between the two groups.

**Study Design:** Double blinded randomized controlled trial.

**Methods:** Thirty-nine subjects were randomized to receive either dry needling (n = 20) or sham (n = 19) dry needling in addition to hamstring stretching, to all detected hamstring trigger points on two visits. All dependent variables were measured at baseline, immediately post intervention, and 1, 3, and 7 days after the initial treatment. Each subject also performed hamstring stretching three times daily for one week.

**Results:** Significant improvements in hamstring range of motion and all other dependent variables were observed across time regardless of treatment group. However, the lack of significant time by group interactions indicated the improvements were not different between dry needling and sham dry needling groups.

**Conclusions:** The results of the current randomized controlled trial suggest that two sessions of dry needling did not improve hamstring range of motion or other knee pain-related impairments more than sham dry needling in a young active population with atraumatic knee pain.

**Level of Evidence:** Therapy, Level 2

**Keywords:** Flexibility, lower extremity, trigger point

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INTRODUCTION
Flexibility and mobility have long been an integral part of many rehabilitation and fitness training programs for patients with non-traumatic knee pain. Muscle tightness, as it contributes to hip and knee range of motion, can limit the execution of large joint, multi-segmental movements such as squatting, lunging, and deadlifting. A decreased ability to perform these movements could potentially lead to decreased physical performance as well as increased risk of injury.1–3 Kibler4 suggests that where there is a deficiency in a proximal segment of the kinetic chain, changed workloads may be required in the more distal segments in order to preserve the same movement outcome at the most distal segment. If this is the case, patients presenting with overuse or overload injuries of the limbs may also experience dysfunction in more proximal segments.

When compared to healthy controls, patients with non-traumatic knee pain have demonstrated significantly less flexibility of lower extremity soft tissues, including the hamstrings.5,6,7 Hamstring mobility, as it contributes to hip and knee range of motion, is important for the proper execution of functional movement patterns such as squatting, deadlifting, lunging, etc commonly required in athletic and training environments.

Hamstring stretching has been used for many years as a common intervention among physical therapists, athletic trainers, and fitness/coaching professionals to improve mobility at the hip and knee as well as to decrease muscle soreness.8 Numerous studies have examined the duration of a single stretch as well as the period of time required to effect significant improvement in hamstring flexibility utilizing a variety of muscle stretching techniques such as active, passive, and assisted stretching. Little consensus exists in the literature about the optimal period of time needed to show improvements with some studies suggesting as little as 4 weeks and other studies suggesting as many as 12 weeks to effect optimal change.9–11 The immediate effects of an acute bout of stretching on knee range of motion have been observed to only last 3-6 minutes.12,13 One potential cause of restricted range of motion related to local muscle dysfunction is the myofascial trigger point (TP).14 TPs are described as localized hyperirritable areas associated with hypersensitive palpable taut bands located in muscle tissue, and are suggested to contribute to joint range of motion restrictions as well as adversely affect muscle activation.15–19 TPs are further described in the literature as being either active or latent.20 Active TPs can be responsible for local pain as well as referred pain or paresthesia21 and may contribute to spontaneous pain at rest.20 Latent TPs are focal areas of tenderness and tightness in muscle tissue. Unless stimulated by direct contact, muscle activation, or stretching, latent TPs are not responsible for local or referred pain. These TPs may lead to altered muscle activation patterns resulting in limited range of motion or weakness of the muscles involved.14,20,21 TPs may also develop secondary to an excessive release of acetylcholine from motor endplates which has been associated with increased motor endplate noise and resulting muscle fiber knots.16

Dry needling (DN) has emerged as a popular intervention to address muscular pain and dysfunction. While multiple theories exist regarding the physiological mechanisms elicited by DN, the functional effects remain largely anecdotal.22–25 These effects appear to be most pronounced when a local twitch response is elicited.23 A local twitch response is an involuntary spinal cord reflex contraction of muscle fibers following needling of the involved fibers.26,27 While numerous studies exist detailing the benefits of dry needling for pain,18,24,28,29 few studies exist examining the effects on soft tissue flexibility.10,13,27 The primary purpose of this study was to determine if the addition of DN to a standard stretching program results in greater improvements in hamstring flexibility versus stretching alone in patients with atraumatic knee pain over the course of one week. The secondary purpose was to compare changes in knee flexion range of motion while squatting; patient reported changes in knee pain with provocative movements, and self-reported disability. It was hypothesized that subjects who received DN and stretching would have greater improvements in hamstring flexibility, pain, and knee range of motion during a squat compared to subjects who only performed stretching.

METHODS
Participants
Subjects presenting with a chief complaint of atraumatic knee pain were recruited from a direct access physical therapy clinic. Using G Power 3.1.20 we deter-
tially numbered envelopes by an investigator not involved with recruitment or data collection. Treatment allocation was revealed to the investigator performing the intervention after collection of baseline measurements. Subjects and investigators taking all measurements were blinded to the intervention. Subjects were randomly assigned to one of two groups: a DN group and a sham DN group. After completion of all initial measurements, each subject received the assigned treatment. Manual palpation of the bilateral biceps femoris, semitendinosus, and semimembranosus was performed to detect the presence of TPs in the DN group. A provider with greater than three years of DN experience performed dry needling to all detected TPs with the subject in the prone position to allow access to the posterior thigh as well as to maintain blinding of the subject. Subjects included in this study complained of anterior knee, not hamstring-region, pain; all TPs identified were latent TPs. Upon identification of a TP a solid monofilament needle (Seirin Corp., Shizuoka, Japan) was inserted into the skin directed towards the target TP (Figure 2). The needle was then repeatedly “pistonned” (inserted and withdrawn rapidly from each TP) without being fully withdrawn from the skin with the goal of eliciting a local twitch response. Treatment was repeated to produce several local twitch responses and continued until all identified areas of dysfunction had been addressed.

Sham DN was implemented using a standard plastic tube as utilized in regular DN, however, instead of a monofilament needle each tube contained a small disinfected finishing nail. Subjects in the sham DN group were positioned identically to subjects in the DN group. Sham DN was performed at three points over
table a sample size of 36 prior to commencement of the trial. This sample size provided 80% power to detect a change of 10° in range of motion on the active straight leg raise (ASLR) and active knee extension (AKE) with an alpha level of 0.05. Previous authors who have studied hamstring injuries and cervicalgia demonstrated 10-12° changes after one week of treatment in subjects that responded favorably to a DN intervention. The study protocol was approved by the institutional review board of Keller Army Community Hospital (West Point, NY) and registered with ClinicalTrials.gov (ClinicalTrials.gov Identifier: NCT02498704). All participants signed an informed consent form prior to inclusion in the study. Participants’ rights were protected through the duration of the study.

To be included in the study subjects had to present with a chief complaint of atraumatic knee pain with duration of symptoms greater than two weeks. Subjects also had to demonstrate a deficit of at least 20° of knee extension on the AKE test. Hamstring tightness was operationally defined as a greater than 20° loss of knee extension during the AKE test as measured with the subject supine and the femur held at 90° of hip flexion. Additional study inclusion and exclusion criteria are presented in Table 1. A screening physical examination of each knee was performed consisting of a Lachman’s test, Posterior Drawer Test, Valgus and Varus stress a 0° and 30°, Bounce Home Test, McMurray’s Test, and Thessaly Test in order to rule out ligamentous deficiency and/or meniscus tears. Subject flow diagram is presented in Figure 1.

**INTerventions**

The randomization schedule was computer-generated, with assignments placed in opaque, sequentially numbered envelopes by an investigator not involved with recruitment or data collection. Treatment allocation was revealed to the investigator performing the intervention after collection of baseline measurements. Subjects and investigators taking all measurements were blinded to the intervention. Subjects were randomly assigned to one of two groups: a DN group and a sham DN group. After completion of all initial measurements, each subject received the assigned treatment. Manual palpation of the bilateral biceps femoris, semitendinosus, and semimembranosus was performed to detect the presence of TPs in the DN group. A provider with greater than three years of DN experience performed dry needling to all detected TPs with the subject in the prone position to allow access to the posterior thigh as well as to maintain blinding of the subject. Subjects included in this study complained of anterior knee, not hamstring-region, pain; all TPs identified were latent TPs. Upon identification of a TP a solid monofilament needle (Seirin Corp., Shizuoka, Japan) was inserted into the skin directed towards the target TP (Figure 2). The needle was then repeatedly “pistonned” (inserted and withdrawn rapidly from each TP) without being fully withdrawn from the skin with the goal of eliciting a local twitch response. Treatment was repeated to produce several local twitch responses and continued until all identified areas of dysfunction had been addressed.

Sham DN was implemented using a standard plastic tube as utilized in regular DN, however, instead of a monofilament needle each tube contained a small disinfected finishing nail. Subjects in the sham DN group were positioned identically to subjects in the DN group. Sham DN was performed at three points over

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Table 1. *Inclusion and exclusion criteria*

<table>
<thead>
<tr>
<th>Criteria</th>
<th>(a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males and females</td>
<td>History of herniated lumbar disc/radiculopathy</td>
</tr>
<tr>
<td>Age 18-40 DoD beneficiaries</td>
<td>Prior surgery in the hip, knee, or back</td>
</tr>
<tr>
<td>Lack of ≥20 degrees of supine active knee extension</td>
<td>Self-reported pregnancy</td>
</tr>
<tr>
<td>Atraumatic knee pain ≥2 weeks</td>
<td>History of blood borne pathogens/infections disease/active infection</td>
</tr>
<tr>
<td></td>
<td>Metal allergy</td>
</tr>
<tr>
<td></td>
<td>Positive instability tests indicative of ligamentous tear</td>
</tr>
<tr>
<td></td>
<td>Joint line tenderness or positive meniscal tests</td>
</tr>
<tr>
<td></td>
<td>Participants not fluent in English</td>
</tr>
<tr>
<td></td>
<td>Previous history of DN</td>
</tr>
<tr>
<td></td>
<td>Bleeding disorders or current use of anticoagulant medications</td>
</tr>
</tbody>
</table>

---
Total screened, n = 60

Randomized, n = 39

Total Excluded n = 21
Hamstring flexibility n = 10
Previous knee surgery n = 5
Radicular symptoms n = 1
Previously treated with DN n = 5

Allocated to DN group n = 20

Allocated to sham group n = 19

Baseline measures, n = 39
- LEFS
- AKE
- ASLR
- DS ROM/pain
- Step down pain

Follow up #1, 1-2 days post intervention, n = 39
- LEFS
- AKE
- ASLR
- DS ROM/pain
- Step down pain

Follow up #2, 3-4 days post initial intervention, n = 39
- LEFS
- AKE
- ASLR
- DS ROM/pain
- Step down pain

Sham group intervention repeated prior to measurements

Follow up #3, 7-8 days post initial intervention, n = 39
- LEFS
- AKE
- ASLR
- DS ROM/pain
- Step down pain

DN group intervention repeated prior to measurements

Figure 1. Subject recruitment/retention flow diagram. DN, dry needling; LEFS, lower extremity functional scale; AKE, active knee extension; DS, deep squat; ASLR, active straight leg raise; ROM, range of motion
investigators (one to maintain proper test position, the second to record the measurement) were utilized for the AKE. (Figure 3) The involved extremity was held in 90° hip and knee flexion with the contralateral posterior knee in contact with the table. Saunders digital inclinometers (Chaska, Minnesota) were used for measurements. Straps were placed on the distal leg at mid-calf to secure an inclinometer in line with the tibial tuberosity. A second inclinometer was held in place at mid-thigh in order to assure that the subject maintained 90° of hip flexion. The subject was directed to actively extend the knee as far as tolerated without loss of the test position. The distal inclinometer was used to measure knee angle. The test was performed twice and the average of the

Figure 2. Hamstring dry needling. Insertion of monofilament needle into lateral hamstring muscle belly towards suspected trigger point.

the lateral hamstrings and three points over the medial hamstrings without the intention of locating any TPs. Similar technique to the DN was used to include a pistoning motion but the skin was not punctured at any time in this group. The same investigator measured each subject at every time point. The assigned treatment was repeated one additional time in the identical manner as detailed above three days later.

Post-intervention, all subjects were given a standing hamstring stretch to perform one repetition held for 30 seconds, repeated three times daily. These parameters have been shown to be effective at improving hamstring flexibility. The stretched was performed with the involved leg elevated on a chair or stool. While standing tall, maintaining neutral spine posture, and keeping the involved knee in full extension, subjects were instructed to lean forward hinging at the hips until moderate stretch discomfort in the hamstrings was felt. Subjects were instructed by demonstration and were provided with a handout of stretching instructions to perform at home. Subjects were also provided with an exercise log to record home exercise compliance.

OUTCOMES

The primary outcome measure was hamstring flexibility (as measured by the AKE and ASLR). Two

Figure 3. (a.) Active knee extension test. Vertical position of the thigh is maintained with one goniometer. (b.) Active knee extension test. Active knee extension angle is measured with a second goniometer.
Secondary outcome measures included pain reported during basic functional tasks and self-reported function on the Lower Extremity Functional Scale (LEFS). Following hamstring measurements, subjects performed a deep squat. Subjects started with feet shoulder width apart, shoulders flexed to 90°, and elbows fully extended. While maintaining heels in contact with the ground, subjects were instructed to squat as deeply as possible or until an increase in knee pain was experienced. Knee flexion was measured at that point with a standard goniometer. Subjects recorded knee pain during the squat on the Visual Analog Scale (VAS). The VAS is a valid and reliable tool for measuring acute and chronic pain.

Next, subjects performed a single leg step down from a 15 centimeter step. Standing on the involved leg, subjects performed a controlled eccentric step down in their normal manner to the uninvolved leg. Subjects recorded knee pain during the step down on the VAS. An investigator blinded to group assignment performed all measurements.

Self-reported knee pain and function were assessed in all subjects at initial enrollment with the LEFS. The LEFS is a self-report questionnaire assessing initial function, ongoing progress, and outcomes concerning 20 different tasks ranging from activities of daily living to hobbies and exercise. The LEFS is a reliable and valid tool for assessing outcomes in lower extremity injuries with a minimal clinically important difference of nine points.

Repeat measurements of all variables were obtained at four time points: immediately post intervention, and one day, three days, and seven days following the initial intervention. Prior to measurements on the third visit, an additional session of DN/sham intervention was performed in the identical manner described above. At the final visit, each subject was asked to predict his or her group assignment. All measurements performed pre-intervention were repeated post-intervention in both groups by the same investigator who remained blinded to group assignment.

**DATA ANALYSIS**

Data analysis was performed with statistical analysis software R version 3.0.2 and SPSS version 18 (Chicago, IL). Means, standard deviations, and 95% confidence intervals (CIs) were calculated for each variable.
A 2×5 mixed model analysis of variance (ANOVA) with Sidak’s post hoc testing was used for each outcome measures with time (pre and post intervention, follow up 1, 2, and 3) as the within-subject factor and group (DN or sham DN) as the between-subject factor. Intraclass correlation coefficients (ICCs), model [3,2] were calculated to ensure intra-rater reliability for AKE and ASLR measurements.

RESULTS

Sixty consecutive patients with atraumatic knee pain were screened for eligibility criteria between January and September 2015. Thirty-nine patients (37 males, 2 females) met the inclusion criteria and agreed to participate. Subjects were randomly assigned to the DN group (n = 20) or a sham DN group (n = 19). Baseline statistics for the DN and sham DN group are found in Table 2. No subjects were lost to follow up after initial enrollment and no adverse events were reported. All participants were analyzed in the groups to which they were assigned. Upon visual inspection of the data there appeared to be a difference in baseline pain with step down between the sham (mean VAS 10.5) and DN (mean VAS 22.84) groups. Because of this potential difference analysis of covariance (ANCOVA) was utilized to assess differences in pain with step down. Otherwise, no statistically significant differences were observed between groups at baseline. Substantial intra-rater reliability for AKE and ASLR was demonstrated for both investigators. ICCs for investigator 1 and 2 were between 0.89 and 0.99 for AKE and ASLR respectively.

The 2-by-5 ANOVA failed to show a significant time by group interaction for AKE (F = 0.83, p = 0.51), ASLR (F = 0.29, p = 0.89), deep squat ROM (F = 0.69, p = 0.60), pain with deep squat (F = 0.58, p = 0.67) and self-reported function (F = 1.73, p = 0.17). The results of the 2-by-5 ANCOVA for pain during a step down also failed to demonstrate a significant difference between groups (F = 2.30, p = 0.47).

A statistically significant main effect for time was observed overall suggesting improvements in AKE (F = 3.94, p < 0.01), ASLR (F = 4.04, p < 0.01), deep squat ROM (F = 10.34, p < 0.001), pain with deep squat (F = 11.44, p < 0.001), pain during a step down (F = 8.78, p < 0.001), and self-reported function (F = 12.79, p < 0.001) across all participants. Post hoc comparisons with Sidak corrections also demonstrated statistically significant improvements from baseline to final follow up for both groups in all variables. Statistically significant improvements in pain and ROM with deep squat were demonstrated for both groups at all time points compared to baseline. Outcome data for primary and secondary outcome measures are presented in Table 3.

DISCUSSION

The outcomes of the current randomized controlled trial suggest that two sessions of hamstring DN with daily stretching for one week did not result in larger improvements in ROM, pain, and self-reported function compared to daily stretching and sham needling in patients with atraumatic knee pain. Participants in both groups demonstrated statistically significant improvements across all measures at the final follow up when compared to baseline. These observations may be a result of hamstring stretching, sham DN, or simply the passage of time, however, which of these influenced the results cannot be known, because a group that received no intervention was not included in this study.

These results are consistent with previous observations of Huguenin et al, who reported no sig-

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**Table 2. Baseline and descriptive statistics by group**

<table>
<thead>
<tr>
<th></th>
<th>Baseline Mean (± SD) DN Group</th>
<th>Baseline Mean (± SD) Sham Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>20.3 (1.08)</td>
<td>20.16 (2.12)</td>
</tr>
<tr>
<td>Gender</td>
<td>20 male</td>
<td>17 male 2 female</td>
</tr>
<tr>
<td>Duration of symptoms (weeks)</td>
<td>17.75 (26.10)</td>
<td>14.3 (16.36)</td>
</tr>
<tr>
<td>AKE (degrees)*</td>
<td>47.72 (9.70)</td>
<td>49.59 (17.10)</td>
</tr>
<tr>
<td>ASLR (degrees)*</td>
<td>52.26 (10.84)</td>
<td>55.33 (13.35)</td>
</tr>
<tr>
<td>Deep Squat ROM (degrees)*</td>
<td>110.35 (24.73)</td>
<td>108.50 (24.18)</td>
</tr>
<tr>
<td>Deep Squat pain (VAS)*</td>
<td>22.40 (22.79)</td>
<td>24.11 (24.75)</td>
</tr>
<tr>
<td>Step Down pain (VAS)*</td>
<td>10.50 (14.27)</td>
<td>22.84 (22.34)</td>
</tr>
<tr>
<td>LEFS Score</td>
<td>65.35 (10.47)</td>
<td>64.47 (10.78)</td>
</tr>
</tbody>
</table>

DN = dry needling  *Measurements taken on the symptomatic limb  AKE = active knee extension  ASLR = active straight leg raise  ROM = range of motion  LEFS = lower extremity functional scale
Table 3. Outcome data for LEFS, ROM, and pain by group

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline mean (± SD)</th>
<th>Post treatment mean (± SD)</th>
<th>FU 1 mean (± SD)</th>
<th>FU 2 mean (± SD)</th>
<th>FU 3 mean (± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DN group AKE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Baseline</td>
<td>47.72 (9.70)</td>
<td>48.68 (13.34)</td>
<td>50.34 (11.48)</td>
<td>49.31 (9.38)</td>
<td>55.51 (12.66)</td>
</tr>
<tr>
<td>Post treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sham</td>
<td>49.59 (17.10)</td>
<td>52.98 (9.64)</td>
<td>52.64 (9.25)</td>
<td>54.73 (7.41)</td>
<td>55.20 (7.68)</td>
</tr>
<tr>
<td><strong>Within-group change score from baseline</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>--</td>
<td>0.96 (-6.51, 8.43)</td>
<td>2.62 (-4.18, 9.42)</td>
<td>1.59 (-4.52, 7.70)</td>
<td>7.79 (0.57, 15.01)</td>
</tr>
<tr>
<td>Post treatment</td>
<td></td>
<td>3.39 (-5.74, 12.52)</td>
<td>3.05 (-6.00, 12.10)</td>
<td>5.14 (-3.53, 13.81)</td>
<td>5.61 (-3.11, 14.33)</td>
</tr>
<tr>
<td>Sham</td>
<td></td>
<td>3.89 (-1.02, 5.16)</td>
<td>2.71 (-7.12, 6.36)</td>
<td>-2.43 (-10.02, 5.16)</td>
<td>2.18 (-4.66, 9.02)</td>
</tr>
<tr>
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<td></td>
<td></td>
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</tr>
<tr>
<td>DN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>52.26 (10.84)</td>
<td>55.32 (12.43)</td>
<td>55.60 (7.50)</td>
<td>57.00 (8.08)</td>
<td>59.47 (9.41)</td>
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<tr>
<td>Post treatment</td>
<td></td>
<td>55.82 (8.38)</td>
<td>57.71 (7.87)</td>
<td>59.00 (6.82)</td>
<td>59.43 (6.88)</td>
</tr>
<tr>
<td>Sham</td>
<td>55.33 (13.35)</td>
<td>56.82 (8.38)</td>
<td>56.02 (7.50)</td>
<td>57.02 (8.08)</td>
<td>59.47 (9.41)</td>
</tr>
<tr>
<td><strong>Within-group change score from baseline</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DN</td>
<td></td>
<td>3.02 (-4.45, 10.49)</td>
<td>3.34 (-2.63, 9.31)</td>
<td>4.74 (-1.38, 10.86)</td>
<td>7.21 (0.71, 13.71)</td>
</tr>
<tr>
<td>Baseline</td>
<td></td>
<td>1.49 (-5.84, 8.82)</td>
<td>2.38 (-4.83, 9.59)</td>
<td>3.67 (-3.31, 10.65)</td>
<td>4.10 (-2.89, 11.09)</td>
</tr>
<tr>
<td>Post treatment</td>
<td></td>
<td>1.53 (-3.43, 6.49)</td>
<td>0.96 (-4.03, 5.95)</td>
<td>1.07 (-3.79, 5.93)</td>
<td>3.11 (-2.26, 8.48)</td>
</tr>
<tr>
<td>Sham</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><strong>Within-group change score from baseline</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>DN</td>
<td>110.35 (24.73)</td>
<td>114.73 (24.44)</td>
<td>120.85 (23.86)</td>
<td>121.78 (23.87)</td>
<td>123.30 (23.54)</td>
</tr>
<tr>
<td>Baseline</td>
<td>108.50 (24.18)</td>
<td>115.21 (23.74)</td>
<td>114.90 (21.85)</td>
<td>122.03 (17.08)</td>
<td>119.92 (20.64)</td>
</tr>
<tr>
<td>Post treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sham</td>
<td>108.50 (24.18)</td>
<td>115.21 (23.74)</td>
<td>114.90 (21.85)</td>
<td>122.03 (17.08)</td>
<td>119.92 (20.64)</td>
</tr>
<tr>
<td><strong>Within-group change score from baseline</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DN</td>
<td></td>
<td>4.38 (-11.35, 20.11)</td>
<td>10.50 (-5.06, 26.06)</td>
<td>11.43 (-4.13, 26.99)</td>
<td>12.95 (-2.51, 28.41)</td>
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<tr>
<td>Baseline</td>
<td></td>
<td>6.71 (-9.06, 22.48)</td>
<td>6.40 (-8.76, 21.56)</td>
<td>13.53 (-0.24, 27.30)</td>
<td>11.42 (-3.37, 26.21)</td>
</tr>
<tr>
<td>Post treatment</td>
<td></td>
<td>-2.33 (-17.97, 13.31)</td>
<td>4.10 (-10.77, 18.97)</td>
<td>-2.10 (-15.63, 11.43)</td>
<td>1.53 (-12.87, 15.93)</td>
</tr>
<tr>
<td>Sham</td>
<td></td>
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</tr>
<tr>
<td><strong>Within-group change score from baseline</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DN</td>
<td>22.40 (22.79)</td>
<td>15.48 (20.71)</td>
<td>10.50 (15.25)</td>
<td>8.60 (14.82)</td>
<td>8.95 (16.19)</td>
</tr>
<tr>
<td>Baseline</td>
<td>24.11 (24.75)</td>
<td>19.42 (23.14)</td>
<td>18.21 (20.70)</td>
<td>13.63 (18.89)</td>
<td>14.95 (20.96)</td>
</tr>
<tr>
<td>Post treatment</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Sham</td>
<td>24.11 (24.75)</td>
<td>19.42 (23.14)</td>
<td>18.21 (20.70)</td>
<td>13.63 (18.89)</td>
<td>14.95 (20.96)</td>
</tr>
<tr>
<td><strong>Within-group change score from baseline</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DN</td>
<td></td>
<td>-6.92 (-20.86, 7.02)</td>
<td>-11.90 (-24.31, 0.51)</td>
<td>-13.80 (-26.11, -1.49)</td>
<td>-13.45 (-26.10, -0.80)</td>
</tr>
<tr>
<td>Baseline</td>
<td></td>
<td>-4.69 (-20.45, 11.07)</td>
<td>-5.90 (-20.76, 8.96)</td>
<td>-10.48 (-24.97, 4.01)</td>
<td>-9.16 (-24.25, 5.93)</td>
</tr>
<tr>
<td>Post treatment</td>
<td></td>
<td>-2.23 (-16.46, 12.00)</td>
<td>-6.00 (-17.75, 5.75)</td>
<td>-3.32 (-14.30, 7.66)</td>
<td>-4.29 (-16.40, 7.82)</td>
</tr>
<tr>
<td>Sham</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><strong>Within-group change score from baseline</strong></td>
<td></td>
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</tr>
</tbody>
</table>
In addition, the hamstrings of the included subjects were not directly injured unlike the subjects of other studies who had muscles treated that were directly involved in an injury. This may explain in part the conflicting results between studies.

It is noteworthy that when asked, 85% (17/20) of subjects in the experimental group, correctly identified true DN, whereas 89.5% (17/19) of subjects in the sham group identified sham DN. The current results indicating no changes in ROM for hamstrings are contrary to previous studies demonstrating significant changes in upper extremity and cervical ROM following DN intervention.\(^29,42,43\)

It is possible that mobility limited by pain rather than muscle dysfunction may demonstrate larger improvements in ROM following DN intervention.

### Table 3. Outcome data for LEFS, ROM, and pain by group (continued)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline mean (± SD)</th>
<th>Post treatment mean (± SD)</th>
<th>FU 1 mean (± SD)</th>
<th>FU 2 mean (± SD)</th>
<th>FU 3 mean (± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DN group step down pain (VAS)</td>
<td>10.50 (14.27)</td>
<td>6.95 (10.17)</td>
<td>8.05 (10.10)</td>
<td>6.00 (10.40)</td>
<td>6.15 (10.62)</td>
</tr>
<tr>
<td>Sham group step down pain (VAS)</td>
<td>22.84 (22.34)</td>
<td>18.32 (20.79)</td>
<td>15.00 (18.19)</td>
<td>10.53 (17.13)</td>
<td>12.95 (18.76)</td>
</tr>
<tr>
<td>Between-group change score from baseline</td>
<td>--</td>
<td>-3.55 (-11.48, 4.38)(^a)</td>
<td>-2.45 (-10.36, 5.46)(^a)</td>
<td>-4.50 (-12.49, 3.49)(^a)</td>
<td>-4.35 (-12.40, 3.70)(^a)</td>
</tr>
<tr>
<td></td>
<td>--</td>
<td>-4.52 (-18.72, 9.68)(^a)</td>
<td>-7.84 (-21.24, 5.56)(^a)</td>
<td>-12.31 (-25.41, 0.79)(^a)</td>
<td>-9.89 (-23.46, 3.68)(^a)</td>
</tr>
<tr>
<td>Between-group difference in change score</td>
<td>--</td>
<td>0.97 (-9.56, 11.50)(^a)</td>
<td>5.39 (-4.09, 14.87)(^a)</td>
<td>7.81 (-1.33, 16.95)(^a)</td>
<td>5.54 (-4.29, 15.37)(^a)</td>
</tr>
<tr>
<td>DN group LEFS</td>
<td>65.35 (10.47)</td>
<td>--</td>
<td>67.75 (8.32)</td>
<td>70.95 (6.14)</td>
<td>72.30 (5.97)</td>
</tr>
<tr>
<td>Sham group LEFS</td>
<td>64.47 (10.78)</td>
<td>--</td>
<td>67.11 (9.65)</td>
<td>66.53 (10.65)</td>
<td>69.26 (11.37)</td>
</tr>
<tr>
<td>Between-group change score from baseline</td>
<td>--</td>
<td>-11.37 (-21.90, -0.84)(^a)</td>
<td>-6.95 (-16.43, 2.53)(^a)</td>
<td>-4.53 (-13.67, 4.61)(^a)</td>
<td>-6.80 (-16.63, 3.03)(^a)</td>
</tr>
</tbody>
</table>

\(*\) mean (95% confidence interval)  \(†\) calculations based on ANCOVA adjusted mean

---

significant changes in straight leg raise or hip internal rotation following gluteal DN or sham DN. The current results indicating no changes in ROM for hamstrings are contrary to previous studies demonstrating significant changes in upper extremity and cervical ROM following DN intervention.\(^29,42,43\)

It is possible that mobility limited by pain rather than muscle dysfunction may demonstrate larger improvements in ROM following DN intervention. In addition, the hamstrings of the included subjects were not directly injured unlike the subjects of other studies who had muscles treated that were directly involved in an injury. This may explain in part the conflicting results between studies.

It is noteworthy that when asked, 85% (17/20) of subjects in the experimental group, correctly identified true DN, whereas 89.5% (17/19) of subjects in
the sham group incorrectly identified true DN. For future studies utilizing sham needling, these results indicate this methodology could be repeated as subjects unfamiliar with this treatment are not likely to know the difference between sham and true needling. These results also suggest that improvement via placebo effect or patient expectations with treatment cannot be ruled out as previous studies have demonstrated positive results may be based on positive expectations of the subject.44

There are a number of limitations in this study. First, DN was only performed twice and to only one muscle group. More demonstrable effects of DN may potentially have been observed with increased frequency and longer duration of treatment and/or treatment of multiple muscle groups involved in hip/knee ROM. While observation of the immediate effect of DN on HS flexibility was desired, a one week follow up period may not have been sufficient to detect overall differences in changes between groups. Second, subjects with atraumatic knee pain of varying origins/sources were included in this study. Hip/core weakness, strength imbalance, and impaired neuromuscular control and timing have also been suggested as contributing factors to apparent hamstring inflexibility and anterior knee pain.45–48 These additional contributory factors were not assessed in this population. Additional methods of needling to include treatment of corresponding spinal levels as proposed by Gunn49 were not performed. It is not unreasonable to hypothesize that utilizing various applications of this modality to a more clearly defined diagnostic criterion may yield different results.

Finally, mean duration of symptoms was sixteen weeks (2-104 weeks) and median duration was four weeks. Potential differences may be observed among a population with more chronic symptoms. Finally, detection of the presence of trigger points was not attempted prior to enrollment as part of this study's inclusion criteria as previous studies have failed to establish adequate reliability for detection with physical exam.50 Consequently, subjects without active trigger points in the HS may have been included. If an insufficient number of trigger points are present within the treated musculature, potential effects of DN may not be as demonstrable.

The results of this study are not conclusive with regard to the effect of DN on hamstring flexibility. While not statistically significant, the 95% confidence intervals for the between group difference change score for the AKE (-4.66, 9.02) and ASLR (-2.26, 8.48) include a potentially clinically meaningful change. As a result, research investigating muscle flexibility changes associated with DN may warrant further consideration.

Future research is needed to investigate the characteristics of subgroups of the population (acute versus chronic injury, physical/psychosocial attributes) that respond favorably to this intervention and more clearly identify those more likely to experience most favorable outcomes. In addition, DN research should aim to identify optimal treatment parameters and the effectiveness of DN in various body regions and musculoskeletal conditions.

CONCLUSION

The results of the current randomized controlled trial suggest that two sessions of DN and daily stretching did not result in larger improvements in hamstring ROM, pain, and self-reported function compared to daily stretching and sham DN, over one week, in a young active population with atraumatic knee pain. Although potentially relevant within-group changes were observed, it is unclear whether these changes were a result of treatment or merely the result of passing time. Additional research is needed to more clearly define the effects of DN on tissue flexibility for different body regions as well as to identify subgroups of the population more likely to obtain optimal outcomes following DN intervention.

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ABSTRACT

Background and Purpose: Achilles tendinopathy can be a debilitating chronic condition for both active and inactive individuals. The identification of risk factors is important both in preventing but also treating tendinopathy, many factors have been proposed but there is a lack of primary epidemiological data. The purpose of this study was to develop a statement of expert consensus on risk factors for Achilles tendinopathy in active and sedentary patient populations to inform a primary epidemiological study.

Study design: Delphi study

Methods and Measures: An online Delphi study was completed inviting participation from world tendon experts. The consensus was developed using three rounds of the Delphi technique. The first round developed a complete list of potential risk factors, the second round refined this list but also separated the factors into two population groups – active/athletic and inactive/sedentary. The third round ranked this list in order of perceived importance.

Results: Forty-four experts were invited to participate, 16 participated in the first round (response rate 40%) and two dropped out in the second round (resulting in a response rate of 35%). A total of 27 intrinsic and eight extrinsic risk factors were identified during round one. During round two only 12 intrinsic and five extrinsic risk factors were identified as important in active/athletic tendinopathy while 14 intrinsic and three extrinsic factors were identified as important for inactive/sedentary tendinopathy.

Conclusions: Risk factors for Achilles tendinopathy were identified based on expert consensus, and these factors provide a basis for primary epidemiological studies. Plantarflexor strength was identified as the primary modifiable factor in the active/athletic group while systemic factors were identified as important in the inactive/sedentary group, many of the potential factors suggested for either group were non-modifiable. Non-modifiable factors include: previous tendinopathy, previous injury, advancing age, sex, steroid exposure, and antibiotic treatment.

Level of evidence: Level V

Key words: Achilles tendinopathy, Delphi study, risk factors
INTRODUCTION

Achilles tendinopathy (AT) is a chronic potentially debilitating condition that can persist for years, preventing people from participating in physical activities like walking and running. It affects 2% of the general population1 and may have a lifetime prevalence of 42% in more active groups2 with most authors reporting 7-12% point prevalence rates in active/athletic individuals.3,4 While the current data supports a higher prevalence in active groups there is a suggestion that only 35% of AT cases presenting to General Practitioner's (GP's) are linked to sports participation.1 This apparent discrepancy may be related to sporting individuals bypassing their GP's and seeking care outside of the normal health care system or may be the result of GP's failing to identify or seek appropriate sporting activities and hobbies during a subjective examination. An important aspect of risk factor analysis is the understanding etiology of tendinopathy. The most accepted theoretical patho-etiological model is the “continuum model”,5 although others exist.6,7 The common feature of these models is excessive loading causing a loss of tissue homeostasis8 although the iceberg model6 and Fu et al’ suggest inflammatory involvement and failed healing while the continuum model fails to accept inflammatory mediated reactions. Instead the continuum model proposes a cell mediated reaction devoid of inflammatory components.5,9 This effectively leads to an active process of degenerative change involving pathways associated with inflammation.10-12 This “cell mediated reaction” is a biochemical cascade leading to alterations in structure and function of the affected tendon.5,9,13 Essentially, tendinopathy seems to link to the rate of wear being greater than the rate of repair.13,14 This simple theory can be used to hypothesise risk factors into two groups; those that increase wear, and those that limit the repair process. An example disorder affecting the ability of the tendon to repair is diabetes. Diabetes is thought to alter the glycation of collagen within tendons affecting their structural integrity, thereby reducing the capacity of the tendon to tolerate load,15 whereas training loads (distance, intensity, duration) influence the rate of wear on the tissue causing some transient degradation in collagen content.16,17 In vivo human research supports these models and confirms a net degradation in collagen after loading.6-18 The current literature also suggests a split in risk factors between the two common clinical groups – inactive/sedentary versus active/athletic individuals. The active group may be more influenced by extrinsic factors such as training errors while the inactive/sedentary group is thought to be influenced by intrinsic factors that are often systemic e.g. inflammatory arthropathies or diabetes mellitus.

In recent years there has been an increase in studies examining risk factors for AT, the majority of these are cross sectional, often termed association studies19-28 rather than longitudinal studies, which are often prospective in nature.20-34 The two types of studies have different uses. Association studies develop information about relationships between diseases and variables whilst prospective studies allow some measure of the cause and effect relationship to be established. The current literature suggests that risk factors for the development of AT may include: sex,35-37 advancing age,14,35,39 obesity,32,38,40,41 diabetes mellitus,42 genetics,43 high cholesterol,38,44 hypertension,42,45 tendon structure,31 hormone replacement therapy,46,47 the use of female contraceptive pills,48 early menopause,47 steroid and antibiotic exposure,38,49 recent injuries or previous tendinopathy,50 foot pronation,51 dorsiflexion range of motion,34,52,53 altered gait kinematics and kinetics,54 rheumatological disease,55 previous sciatica, “training errors” and alterations to activity levels, both higher and lower,50 footwear,20 environmental factors like temperature,56 training surfaces,57,58 and muscle strength.29,34 Unfortunately many of these factors are not based on primary epidemiological data and often represent author opinion. Two systematic reviews exist in the area with one addressing biomechanical alterations54 and the other focusing solely on runners.50 Neither of these reviews identified many strong risk factors, as the evidence is weak for most variables.

Only prospective studies can be used to make conclusions about causality, unfortunately there are few prospective studies and of those that exist seem to have used a “fishing” approach to the variables examined. This has led to the identified variables lacking plausible biological explanations. Many of the reported variables relate only to the individual researcher’s beliefs and assumptions about the
etiology of AT, although occasionally the studies are informed by previous research findings. Although a systematic review is an appropriate method to identify the current state of evidence it has a limited value in examining current theories and informing future directions as it can only report the current literature. The lack of identification of new risk factors for AT has caused some stagnation in the list of risk factors being investigated, in particular with regard to preventative studies. Because of the inconclusive findings and lack of full and total consideration of all possible risk factors further research is needed to address this gap. In areas such as AT where there is limited literature/evidence substantiating risk factors it is appropriate to develop an expert consensus. The development of expert consensus is best done using a Delphi technique as all members of the panel can offer their opinion without hierarchical issues affecting decisions. A Delphi technique involves the collection of expert opinion using structured or semi-structured rounds of questioning leading to a consensus of opinion, particularly useful for informing clinical decision-making. The views of world experts were deemed more appropriate than those of informed individuals as the experts are those publishing the studies whose findings are being disseminated to the “informed individuals”. These same experts are influencing others research agendas, either through reviewing grant applications, peer review of publications, conference presentations, or simply through their own research teams. Effectively these experts set the “trend” for further research and as such they provide an important group whose opinions are worthy of examination.

The purpose of this study was to develop a statement of expert consensus on risk factors for AT in active and sedentary patient populations to inform a primary epidemiological study. This was to include previously identified factors and also new possibilities. The identified factors could then be used to inform further epidemiological research.

METHOD

Study design
This study used a Delphi design of world tendon experts. Ethical approval was given through the University of Leicester ethics review panel.

Participants
Purpose sampling was used to identify world’s leading tendon experts who had published at least two research papers on AT in the prior 10 years. Potential participants were from a clinical background and included Sports medicine physicians, surgeons or physical therapists. The potential participants were identified from published articles by using a search involving Achilles tend* as this identifies all versions of tendon, (e.g. tendinitis, tendinosis, tendonosis, tendinopathy etc) on electronic databases including CINAHL, Medline, Sports Discuss, and Scopus. In total 44 world tendon experts were identified as suitable participants. The majority of these experts were highly influential academics with long career histories. Contact information was extracted from publications and initial emails sent to determine interest. Informed consent was obtained and the rights of individuals were preserved. In order to maintain anonymity for the experts in this study they have not been named, in an attempt to show their academic “quality” we have provided information on their H index based on the 10-year period prior to the study. The H index is a measure of impact of individual academics. The numerical ranking expresses how many articles they have produced that have been cited that number of times. This means that an H index of 10 equates to ten publications with ten citations each. The Achilles tendon experts included in this study had H index ranging from 3-66 when assessed using the Scopus database. Isolating the H index of the participants to only their tendon papers reduces the H number, with the highest-ranking author having an index of 19 and the lowest ranking participant an index of 2. Ten of the participants ranked within the top 60 Achilles tendon experts identified by www.expertscape.com, a website which ranks clinical and academic medical professionals based on their publications. It is important to note that many of the academics on the Expertscape website did not meet the participant inclusion criteria as they were basic scientists and not clinicians. Using the data from the subjects H index and Expertscape ranking it is clear that the study successfully recruited world leading Achilles tendon experts.

Procedure
An initial literature review was completed to identify potential risk factors; these factors were formulated
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Risk Factors for Achilles Tendinopathy - Opinions of World Tendon Experts

First Round

Participants (N=44) invited by email.

Participants (N=16) assessed the suggested risk factors and added any other factors.

Due to the ambiguity of the term “Training errors” experts who identified this risk factor were asked to specify components they considered e.g. training distance, alterations in training etc.

Second Round

Participants were emailed the results of the first round.

Participants (N=14) reviewed the results and identified which factors were relevant for two distinct patient populations - Active/Athletic individuals and Inactive/Sedentary.

During the second round respondents identified muscle power as one of the few modifiable factors and as many of the intrinsic and extrinsic factors may be confounded by strength or muscle endurance it was deemed appropriate to ask if respondents considered strengthening exercises of the Triceps Surae to be preventative of Achilles tendinopathy.

Risk factors that were identified by less than 40% of respondents were removed from the next round.

Third Round

Participants were emailed the results of the second round.

Participants ranked risk factors in priority order for each of the distinct patient populations - Active/Athletic individuals and Inactive/Sedentary.

Results of the third round were reported back to respondents.

Figure 1.

into the first Delphi round. A flow chart of the procedure can be seen in Figure 1. This review identified factors from previous association and prospective cohort studies. In total, 17 intrinsic and eight extrinsic risk factors were identified in the literature. This list was distributed to all 44 identified experts via an online survey tool (Qualtrics). Four emails were returned “unable to deliver” and these four experts were removed from the panel list. The survey ran from October 2012 to January 2013.
The first round asked respondents to identify relevant factors from the disseminated list that they felt were of importance, and they were asked to add any other factors they felt were important but not already listed. These additional factors were then added to the existing list and used for round two. The ability of experts to identify any other factors omitted from the first round is highly recommended for Delphi studies and helps ensure a valid complete set of factors.65 A commonly identified extrinsic risk factor in previous studies was “training errors”, however there is no clear operational definition of this term. In an attempt to develop knowledge around factors considered as “training errors” those participants who identified “training errors” as a factor were directed to a further question determining which specific components they considered important, this included: weekly distance, years in sport, recent alterations in training, change in type of activity, alterations in amount of activity, or accumulation of time active/inactive.

Round two asked participants to identify which factors from the full list they felt were applicable. In addition to this information the study sought to distinguish risk factors for two distinct groups-an Active/Athletic group and an Inactive/Sedentary group. For the purposes of this study we defined an: Active/athletic individual as someone who participates in vigorous physical activity a minimum of three times per week. Conversely, inactive/sedentary individual were defined as those individuals who do not participate in physical activity or hobbies.

Factors not identified by 40% or more of the panel as applicable were removed, in keeping with the Delphi technique.65,66 During the second round respondents identified muscle power as one of the few modifiable factors and as many of the intrinsic and extrinsic factors may be confounded by strength or muscle endurance it was deemed appropriate to ask whether respondents considered strengthening exercises of the Triceps Surae to be preventative of AT. This question was asked for both the Active/Athletic and Inactive/Sedentary groups. Respondents were asked to justify their answer to this question for both populations during the second round.

The third round focussed on ranking in priority order the factors experts considered most important. This round involved intrinsic and extrinsic factors and was ranked separately for the two populations -active/athletic and inactive/sedentary.

**Data Analysis and feedback**

In between each round respondents were provided with the results of the previous round. This is recommended in Delphi technique as it helps participants consider their response in light of their peers.65-68 However the anonymous nature of this feedback helps to reduce bias often inadvertently caused by perceived hierarchical roles.66 The data was analysed using simple descriptive methods. Email reminders were sent to participants in an attempt to increase participation levels. A limit was set at two email requests so that the respondents did not feel inappropriately pressured,69,70 as required by the ethics approval and is recommended as a valid way of increasing response rates. Each round ran for a total of two weeks.

**RESULTS**

**Participants**

Round 1 was comprised of 16 participants from the initial 40 who were contacted, a response rate of 40%. All 16 respondents were active clinical researchers-eight physical therapists, five consultant surgeons, two Sports Medicine Physicians, and one Exercise Physiologist. The second and third rounds had 14 participants, a response rate of 35%. It is unclear why two individuals were lost to follow up between rounds 1 and 2 as no response was forthcoming to the reminder emails. The two drop outs were one physical therapist and one consultant surgeon.

**Round 1**

Round 1 started with 17 Intrinsic and eight extrinsic factors, and a further 10 intrinsic factors were identified by respondents. If respondents ticked “training errors” they were asked another question seeking to identify what elements they considered within this category, this also allowed further choices to be added. The “training errors” had six components initially proposed with a further three added by the experts. Many of these factors could be considered overlapping in nature. These factors were not included in the later rounds as they were under the umbrella term of “training errors”.

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Round 2
Round 2 started with 27 intrinsic factors and eight extrinsic factors, which were then split into the active and inactive groups. All factors were included for both AT populations but experts considered the factors independently for each group. The results are presented separately for both the populations considered.

Round 2 - Active/Athletic
In the active/athletic group only 12 intrinsic and five extrinsic factors were identified by more than 40% of panel and therefore included in round 3, the other factors were removed from the study. Round 3 ranked the factors in order using the 12 Intrinsic factors and five extrinsic factors, and within the extrinsic factors “training errors” were further split. This was an attempt to develop further understanding about what is considered a training error.

Round 2 - Inactive/Sedentary
In round 2 the inactive/sedentary group had 14 of the 27 intrinsic factors identified by 40% or more of panel, these factors then formed the basis for round 3. Of the seven extrinsic factors used in round 2 only three were identified by 40% or more and therefore used in round 3. In this group instead of “training errors” “activity levels” were identified as an issue, due to the lack of definition further clarification was sought with sub categorization into seven factors.

Round 3
 Ranked results are shown for the active/athletic groups split into intrinsic (Table 1) and extrinsic (Table 3) risk factors, while the inactive/sedentary groups intrinsic and extrinsic factors are ranked in Tables 2 and 4 respectively. The extrinsic factor of “training error” for active/athletic tendinopathy and “activity levels” for the inactive/sedentary group were further categorized and ranked, and are displayed in Table 5 for the active/athletic group and Table 6 for the inactive/sedentary group.

DISCUSSION
This Delphi study explored risk factors for AT. The experts who participated in this study suggested that muscle strength/weakness is the primary modifiable risk factor for tendinopathy in an active/athletic population. They also suggested muscle strengthening may be an important preventative

| Table 1. Ranked Intrinsic risk factors for the development of Achilles tendinopathy in active/athletic individuals |
|---|---|---|
| Rank | Risk factor for Achilles tendinopathy | Mean Rank | Rank Range |
| 1 | Previous lower limb tendinopathy | 2.55 | 1-11 |
| 2 | Recent Injury (any tissue) | 3.73 | 2-8 |
| 3 | Advancing Age | 4.18 | 1-10 |
| 4 | Gender | 4.91 | 1-8 |
| 5 | Muscle Power/strength | 5.82 | 2-12 |
| 6 | Steroid Exposure | 7.00 | 1-11 |
| 7 | Reduced ankle dorsiflexion | 7.91 | 1-12 |
| 8 | Weight | 8.00 | 5-11 |
| 9 | Antibiotic treatment (e.g. fluoroquinolones) | 8.09 | 3-12 |
| 10 | Foot Pronation | 8.27 | 3-12 |
| 11 | Obesity | 8.45 | 1-12 |
| 12 | Foot Alignment (e.g. Subtalar joint axis or pes cavus) | 9.09 | 5-12 |

Note: Bold type is used to identify factors that are modifiable. Steroids are considered a non-modifiable factor as they are prescribed for inflammatory disorders, e.g. Rheumatoid Arthritis, which would take precedent over the risk of Achilles tendinopathy. Equally Antibiotic treatment would normally be considered non-modifiable as the quinolone group are normally prescribed for patients with renal impairment and therefore other antibiotics are not suitable. If a healthy (non-renal impaired) individual were prescribed a high risk antibiotic then it would be considered modifiable in that instance.
measure. This clearly links to current therapeutic management and highlights an area where focussed research is needed. The experts suggested that many in the Inactive/sedentary group have factors that are related to systemic changes (age, sex, adiposity, and diabetes). These findings are discussed below.

### Intrinsic Risk Factors for Active/Athletic Tendinopathy

The intrinsic risk factors for the athletic group can be seen in Table 1, the first two relate to previous injuries and are not directly modifiable, however a recent meta-analysis showed that strength training could reduce overuse injuries in the lower limb by 50% and acute injuries by 33%. Therefore the integration of strength training in athletes may well assist modifying these two factors. Strength training was the highest-ranking modifiable factor identified by the experts in this panel. Currently strength training appears to be the mainstay of therapeutic exercise for tendinopathy and the authors of a recent systematic review suggested that neuromuscular adapta-

---

**Table 2. Ranked Intrinsic risk factors for the development of Achilles tendinopathy in inactive/sedentary individuals**

<table>
<thead>
<tr>
<th>Rank</th>
<th>Risk factor for Achilles tendinopathy</th>
<th>Mean Rank</th>
<th>Rank Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Advancing Age</td>
<td>4.64</td>
<td>1-12</td>
</tr>
<tr>
<td>2</td>
<td>Obesity</td>
<td>4.91</td>
<td>1-12</td>
</tr>
<tr>
<td>3</td>
<td>Gender</td>
<td>6.00</td>
<td>1-12</td>
</tr>
<tr>
<td>4</td>
<td>Recent injuries</td>
<td>6.09</td>
<td>2-10</td>
</tr>
<tr>
<td>5</td>
<td>Previous Lower limb tendinopathy</td>
<td>6.27</td>
<td>1-13</td>
</tr>
<tr>
<td>6</td>
<td>Weight</td>
<td>6.55</td>
<td>2-13</td>
</tr>
<tr>
<td>7</td>
<td>Diabetes Mellitus</td>
<td>6.64</td>
<td>3-14</td>
</tr>
<tr>
<td>8</td>
<td>Steroid Exposure</td>
<td>7.64</td>
<td>1-14</td>
</tr>
<tr>
<td>9</td>
<td>High Cholesterol</td>
<td>8.18</td>
<td>3-13</td>
</tr>
<tr>
<td>10</td>
<td>Rheumatological disease</td>
<td>8.45</td>
<td>3-14</td>
</tr>
<tr>
<td>11</td>
<td>Muscle power/strength</td>
<td>9.18</td>
<td>1-14</td>
</tr>
<tr>
<td>12</td>
<td>Antibiotic treatment (e.g. fluoroquinolones)</td>
<td>9.45</td>
<td>2-14</td>
</tr>
<tr>
<td>13</td>
<td>Muscle endurance</td>
<td>10.36</td>
<td>1-14</td>
</tr>
<tr>
<td>14</td>
<td>Reduced Dorsiflexion</td>
<td>10.64</td>
<td>8-14</td>
</tr>
</tbody>
</table>

*Note: Bold type is used to identify factors that are modifiable.*

---

**Table 3. Ranked Extrinsic risk factors for the development of Achilles tendinopathy in Active/Athletic individuals**

<table>
<thead>
<tr>
<th>Rank</th>
<th>Risk factor for Achilles tendinopathy</th>
<th>Mean Rank</th>
<th>Rank Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Changes in loading (e.g. return from closed season/holiday)</td>
<td>1.82</td>
<td>1-3</td>
</tr>
<tr>
<td>2</td>
<td>Training errors (distinct from above, i.e. ramping up)</td>
<td>2.55</td>
<td>1-3</td>
</tr>
<tr>
<td>3</td>
<td>Activity levels (more general)</td>
<td>3.36</td>
<td>1-5</td>
</tr>
<tr>
<td>4</td>
<td>Footwear (barefoot, flat shoes, orthotics)</td>
<td>4.64</td>
<td>3-5</td>
</tr>
<tr>
<td>5</td>
<td>Training surface</td>
<td>4.64</td>
<td>4-5</td>
</tr>
</tbody>
</table>

---

**Table 4. Ranked extrinsic risk factors for the development of Achilles tendinopathy in inactive/sedentary individuals.**

<table>
<thead>
<tr>
<th>Rank</th>
<th>Risk factor for Achilles tendinopathy</th>
<th>Mean Rank</th>
<th>Rank Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Changes in Loading (e.g. trying to get fit)</td>
<td>2.09</td>
<td>1-2</td>
</tr>
<tr>
<td>2</td>
<td>“Activity levels” – e.g. normal level of activity</td>
<td>2.45</td>
<td>1-2</td>
</tr>
<tr>
<td>3</td>
<td>Footwear - flat shoes, orthotics, new footwear</td>
<td>3.00</td>
<td>3</td>
</tr>
</tbody>
</table>
tions are the only consistent potential mechanism of effect. Current data also shows that if rehabilitation from previous tendinopathy is incomplete leaving neuromuscular deficits (functional performance, strength and endurance) these residual strength deficits may explain why previous injury is considered such a risk factor for recurrent tendinopathy. Alternatively the incomplete resolution of structural changes may explain the risk. The third and fourth ranked intrinsic risk factors, advancing age and sex, are not amenable to change, however the link between advancing age and sex and the development of AT may simply be a confounder, with the real issue being age related reductions in strength, rather than age specifically. Age and sex are often mentioned as risk factors for tendinopathy but this has only been studied once, and no link was found between age or sex and tendinopathy. There is also a suggestion that any between sex differences may simply be the result of differences in reporting of injuries or seeking care. This discrepancy between the expert consensus and some of the literature highlights the complex nature of risk factors and the difficulty analyzing the literature.

### Intrinsic Risk Factors for Inactive/Sedentary Tendinopathy

The intrinsic risk factors identified for the inactive/sedentary group (Table 2) differ from the active/athletic group (Table 1). Many of the high-ranking factors in the inactive/sedentary group represent systemic elements. These are all theorized to alter the tissue homeostatic mechanisms leading to reduced capacity to tolerate load. The experts in the study identified weight and obesity as separate factors. The rationale for this is unclear because further information was not sought. However the current literature suggests obesity is linked to an increase in pro-inflammatory cytokines and this is hypothesized to influence tissue homeostasis by influencing repair rates, which seems to be particularly relevant to abdominal adipose tissue. Weight per se is thought to influence the mechanical load on the tissue and therefore is linked to the rate of wear, however, an individual can have a high weight but be non-obese, as is seen in muscular athletic individuals. Some individuals may be the reverse of this - normal weight but large amounts of adipose tissue, specifically around the waist. The reason obe-

<table>
<thead>
<tr>
<th>Rank</th>
<th>Risk factor for Achilles tendinopathy</th>
<th>Mean Rank</th>
<th>Rank Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sudden increases in training levels (layoffs or recovery periods and then return to activity)</td>
<td>1.64</td>
<td>1-5</td>
</tr>
<tr>
<td>2</td>
<td>Changes in type of loading (e.g. hill work)</td>
<td>3.09</td>
<td>1-7</td>
</tr>
<tr>
<td>3</td>
<td>Recent alterations in training due to events/competitions (increase or reductions)</td>
<td>3.18</td>
<td>2-5</td>
</tr>
<tr>
<td>4</td>
<td>Intensity of training sessions</td>
<td>4.73</td>
<td>2-7</td>
</tr>
<tr>
<td>5</td>
<td>Duration of training – length of session</td>
<td>5.09</td>
<td>1-7</td>
</tr>
<tr>
<td>6</td>
<td>Frequency of training sessions</td>
<td>5.09</td>
<td>4-7</td>
</tr>
<tr>
<td>7</td>
<td>Weekly distance</td>
<td>5.18</td>
<td>1-7</td>
</tr>
</tbody>
</table>

### Table 5. A ranked breakdown of what the panel considered as a “training error” for the Active/Athletic individuals.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Risk factor for Achilles tendinopathy</th>
<th>Mean Rank</th>
<th>Rank Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sudden changes in activity levels</td>
<td>2.09</td>
<td>1-4</td>
</tr>
<tr>
<td>2</td>
<td>Recent alterations in activity/inactivity levels</td>
<td>2.45</td>
<td>1-5</td>
</tr>
<tr>
<td>3</td>
<td>Changes in loading (type of activity)</td>
<td>3.18</td>
<td>1-6</td>
</tr>
<tr>
<td>4</td>
<td>Type of activity they normally participate in</td>
<td>4.00</td>
<td>1-6</td>
</tr>
<tr>
<td>5</td>
<td>Activity/inactivity levels - accumulative time</td>
<td>4.09</td>
<td>1-6</td>
</tr>
<tr>
<td>6</td>
<td>Frequency of activity/inactivity</td>
<td>5.18</td>
<td>3-6</td>
</tr>
</tbody>
</table>

### Table 6. A ranked breakdown of what the panel considered within the “activity level” risk factor for the inactive/sedentary individuals.
sity and weight did not feature so highly in the athletic group is that the panel likely perceived most active/athletic individuals to be relatively slim. Many of the factors identified in the sedentary group could be perceived as metabolic syndrome and possibly grouped together. Metabolic syndrome is the combination of abdominal obesity, high cholesterol, diabetes mellitus or insulin resistance and hypertension, it is common that individuals have all of these factors concurrently and each factor may not be independent of the other and therefore best considered as one. Further work is needed to consider this supposition.

Extrinsic Factors
The panel identified similar extrinsic risk factors for both the active/athletic group and the inactive/sedentary group. The majority of factors were linked to tendon loading and were considered under several guises, with changes in loading being consistently ranked first, while more general activity levels came second. Many of the factors identified by the expert panel could be interchangeable between the two groups or indeed amongst themselves, for example, changes in loading could be considered a training error. However these factors were identified by the panel and as such were maintained as separate entities. The “training errors” and “activity level” factors were further separated and the expert panel identified sub-components as the primary factors within these, as displayed in Tables 5 and 6. The relationship between tendinopathy and load has been well documented in the literature and seems to be most commonly associated with active/athletic tendinopathy where the load is quantifiable and alterations to reduce load appear to reduce tendinopathy. Unfortunately, there is very little literature on loading in AT in inactive/sedentary populations.

Does Strength Training Protect Against Achilles Tendinopathy?
Physical activity was identified as a key risk factor during the Delphi study and many of the identified elements may link with muscle strength and endurance capacity being pivotal in AT development. Due to this suggested role of muscle function (strength/endurance), it was deemed appropriate to seek information from the experts about whether they believed strengthening of the plantarflexors was considered protective against AT (Tables 7 and 8). Seventy-nine percent of the panel agreed that strengthening the plantarflexors in the inactive/sedentary group (Table 8) would prevent tendinopathy, despite ranking strength/power as the 11th risk factor. In contrast strength/power was ranked 5th in the active/athletic group but only 57% of the panel thought strength training would be preventative (Table 7). Using the panel's stated rationale for their decisions it appears they perceived athletic individuals to already have good strength while the inactive/sedentary group were perceived as weaker. This perception of the experts seems to assume that because individuals are active they are inherently strong enough for their chosen activity. Currently several authors have concluded that this is not the

| Table 7. Experts responses to whether they considered strength training of the Triceps Surae group as preventative for the development of Achilles tendinopathy in Active/Athletic patients. |
|---|---|---|
| **Answer** | **Number** | **%** |
| Yes | 8 | 57% |
| No | 3 | 21% |
| Unsure | 3 | 21% |

Note: the percentage levels are rounded to a full number, this explains the reason for the missing 1%. This question was asked because strength was identified by the experts as the primary modifiable risk factor in the active/athletic group.

| Table 8. Experts responses to whether they considered strength training of the Triceps Surae group as preventative for the development of Achilles tendinopathy in Inactive/Sedentary patients. |
|---|---|---|
| **Answer** | **Number** | **%** |
| Yes | 11 | 79% |
| No | 2 | 14% |
| Unsure | 1 | 7% |

Note: This question was asked because strength was identified by the experts as the primary modifiable risk factor in inactive/sedentary individuals.
case and clinicians should consider strength in relation to body weight and functional requirements rather than just gross strength.75,82,83

Many of the identified intrinsic and extrinsic factors seem capable of inducing muscle weakness through either over training – “training errors”/“activity modification” or under training/inactivity. Over training could induce muscle weakness by allowing insufficient recovery periods between bouts of activity, studies have shown muscle weakness/fatigue may last for up to 47 days after a single session of exercise. 84 Many of the individuals in this study reported feeling “recovered” despite ongoing neuromuscular (strength, endurance and functional) deficits. It would appear likely than many individuals experience the prolonged neuromuscular deficits with their normal training regimes but fail to acknowledge this residual weakness/fatigue84,85 and inadvertently continue training, thereby increasing the risk of tendinopathy. Undertraining/inactivity would have a similar effect on strength although through other various neuromuscular processes including atrophy. The current literature on adiposity/obesity has focused on systemic changes linked to cytokine levels. It is possible that obesity, particularly abdominal adiposity, increases the stress and strain on the Achilles tendon. This would occur as a consequence of abdominal adiposity moving the centre of mass forwards thereby increasing the load on the Achilles tendon. This alteration in Achilles tendon stress and strain may lead to greater negative tendon adaptation and consequently to tendinopathy. The role muscle strength plays in AT is poorly researched, however, data on army recruits shows that plantarflexor strength is predictive of AT development,34 and plantarflexor weakness has been repeatedly associated with AT.19,23 However it is unknown whether modifying strength alters the risk for tendinopathy, or how it may link to clinical outcome.19,34 Further studies are needed to examine whether strength training is preventative of tendinopathy, as well as to investigate the underlying mechanism behind clinical changes that occur with strength training (loading). The two main clinically feasible explanations for recovery are tendon adaptation,86-89 however this is not supported by current evidence in a recent systematic review,11 or neuromuscular adaptations that help protect the tendon from load.34,72,76,90,91 Unfortunately there is limited evidence assessing alterations in muscle function after therapeutic intervention.

**Limitations of findings**

In interpreting the findings of this study it is important to consider methodological limitations. While the sample size of 14 appears relatively small it must be considered in relation to the number of leading authorities on AT and the number of respondents in other published Delphi studies, with 17 respondents being the average.65 Since the number of world Achilles tendon experts is relatively small a sample size of 14 would have been a reasonable proportion of the overall population size. A response rate of 40% for an online survey is acceptable and of sufficient size to produce meaningful data.65 The expert panel that participated in this study may produce a different list of factors if the methodology were altered to include clinicians rather than published researchers. However this study sought expert opinion due to the lack of empirical evidence. The impact of non-response to the survey is difficult to determine, as no information is available for the rationale for non-response to the initial invitation. In order to improve participation and reduce the burden the study used relatively short rounds. The dropout rate from the start of round one to completion of the study was only two individuals, or 12% drop out rate. The reasons for dropping out are unknown.

It is possible that risk factors were missing from the initial list but an exhaustive review was undertaken and the experts involved were allowed to offer alternative variables, which were then included in the second round of the Delphi. A potential problem with using ranking is many of these factors may be considered in combination with one another and not relative isolation,92 this may make clusters of factors more important in some individuals. A key limitation to the findings is that they represent the opinions of leading experts in the area, and although such findings are useful it is no substitute for carefully conducted prospective epidemiological studies.

This Delphi study did not ask experts to differentiate between insertional and mid-portion tendinopathy. It may be that different factors play different roles for each of these disorders as the disease etiologies are
felt to differ e.g. insertional tendinopathy is felt to be influenced by compression\(^9\) of the Achilles tendon against the calcaneus\(^9,10\) and therefore increased dorsiflexion may play a more pivotal role. However this was not investigated as the current body of risk factor evidence has failed to distinguish between the two zones or types of tendinopathy. By developing a complete list of factors initially it is hoped that further epidemiological studies can distinguish between these two groups more specifically.

Further studies

The ranking of the identified factors helps develop understanding about which factors may be most important in the etiology of AT. This data will help to focus further prospective longitudinal research and also guide clinicians with factors to address during their clinical interventions. While this study has developed new knowledge around risk factors, no cause and effect can be inferred, and it is still unknown why particular factors may increase risk of tendinopathy. Further studies are needed to confirm the suggestions from world experts and then to develop further understanding regarding the underlying pathological processes.

The opinions of international experts are likely to influence the way in which tendon research is conducted through the peer review process for both publication and research grant awards. Careful epidemiological research is required to substantiate these opinions to facilitate objective research. It is through this process that preventative regimes may be developed.

CONCLUSION

This study produces new data regarding potential risk factors for AT. World tendon experts identified the main modifiable risk factor in active/athletic group to be muscle strength, which is supported by some prospective data.\(^34\) A focus on measuring muscle strength/power/endurance in prospective cohorts to determine normal values and what level constitutes a risk appears to have merit. However in inactive/sedentary groups the focus may need to be on obesity, weight, diabetes and cholesterol levels, all of which are systemic risk factors for tendinopathy. While these factors are modifiable in nature, the ability to change these during a normal therapeutic intervention period may be challenging.

REFERENCES


ABSTRACT

Background: Although the relationship of self-efficacy to sports performance is well established, little attention has been paid to self-efficacy in the movements or actions that are required to perform daily activities and prepare the individual to resume sports participation following an injury and associated period of rehabilitation. There are no instruments to measure self-confidence in movement validated in an adolescent population.

Purpose: The purpose of this paper is to report on the development of the AMCaMP, a self-report measure of confidence in movement and provide some initial evidence to support its use as a measure of confidence in movement.

Methods: The AMCaMP was adapted from OPTIMAL, a self-report instrument that measures confidence in movement, which had been previously designed and validated in an adult population. Data were collected from 1,115 adolescent athletes from 12 outpatient physical therapy clinics in a single healthcare system.

Results: Exploratory factor analysis of the 22 items of the AMCaMP using a test sample revealed a three-factor structure (trunk, lower body, upper body). Confirmatory factor analysis using a validation sample demonstrated a similar model fit with the data. Reliability of scores on each of three clusters of items identified by factor analysis was assessed with coefficient alpha (range = 0.82 to 0.94), Standard Error of Measurement (1.38 to 2.74), and Minimum Detectable Change (3.83 to 7.6).

Conclusions: AMCaMP has acceptable psychometric properties for use in adolescents (ages 11 to 18) as a patient-centric outcome measure of confidence in movement abilities after rehabilitation.

Level of Evidence: IV

Keywords: Adolescents, confidence, movement, rehabilitation, self-efficacy
INTRODUCTION

Return to sport is a critical goal in rehabilitating adolescents engaged in athletics. Although these athletes may be most concerned with their abilities to execute the movements essential to their sport, physical rehabilitation of an injury begins with the individual's ability to execute the actions of daily activities (e.g., bending, running, hopping, lifting, reaching) that will eventually support accomplishment of sport-specific tasks (e.g., turn a handspring, shoot a lay-up, throw a pass) properly after the patient returns to athletic engagement.

Although the relationship of self-efficacy to sports performance is well established,1–3 little attention has been paid to self-efficacy in the movements or actions that are required to perform daily activities. These movements, once restored, form the basic “vocabulary” of the sport-specific movements that will eventually allow the individual to resume sports participation. The proper execution of these movements depends in part on an individual's confidence in being able to perform the movement, which may be particularly challenging if the individual has suffered a re-injury. Derived from the broader social psychology literature, self-efficacy was first conceptualized by Bandura,4 who proposed that situation-specific beliefs about one's capabilities to perform specific tasks will help to determine what tasks individuals will choose to do, the energy and attention they will devote to doing it, and the perseverance that will be displayed to execute a specific level of performance when confronted by barriers to success. If one lacks confidence in the ability to move correctly to perform everyday activities, then it is highly unlikely that the athlete will perform more demanding movements of a sport.

Although there is a plethora of infant and child development scales as well as standardized assessments for adults, especially older adults, few instruments have been expressly developed for and validated in adolescent athletic populations.5–7 Such is also the case for instruments that measure self-efficacy, despite the importance of self-efficacy to effective rehabilitation.5 After searching the literature for such an instrument that would be relevant to the movements of daily life and support the various movements required by the particular sport in which these adolescent patients participated, it was concluded that the confidence scale of OPTIMAL9 was a suitable candidate for a general instrument measuring movement self-efficacy that might be validated on adolescent athletes. OPTIMAL has a specific focus on movement, and had known psychometric properties for populations as young as 18 years of age. The purpose of this paper is to report on the development and initial validation of the Adolescent Measure of Confidence and Musculoskeletal Performance (AMCaMP), a self-report measure of confidence in movement.

METHODS

Instrument Development Process

The OPTIMAL confidence scale is a 22-item self-report measure on an individual's confidence in performing 22 basic movements such as rolling, sitting, standing, walking, running, lifting, and carrying. Its psychometric properties were evaluated on 360 individuals over the age of 18. All items were rated on a 1-5 scale (fully confident to no confidence) at initial visit and at discharge. The preliminary draft of the AMCaMP used the same Likert-type scale for each item. Designed as a patient-centric measure that would aid treatment planning for adults, OPTIMAL also contains an item in which respondents are given the opportunity to identify three movements or actions that they would like to perform better. This item was also carried over as a single question to the preliminary draft of AMCaMP.

Although OPTIMAL used a visual analogue scale to make a global assessment of confidence in movement, this question was re-written for the AMCaMP's intended population by eliciting a global estimation of self-efficacy at discharge as it related to return to sport. This global item, “Are you ready to return to your previous level of physical activity?” had a dichotomous response (i.e., yes/no).

Study Sites and Participants

We gathered data from patients who were referred to physical therapy for sport-related injuries from 12 outpatient clinics in the Children's Healthcare of Atlanta (CHOA) system. The institutional review board of CHOA approved the data collection process with exemptions from the institutional review
boards of George Mason University and the Ohio State University. Traditionally the onset of puberty is accepted as the beginning of adolescence, which was arbitrarily operationalized as 11 years of age. All therapists at each site were instructed on who was eligible to participate in the study and how to collect the data. Any new patient was eligible to participate in the study if the patient was: (1) 11 to 18 years of age; (2) spoke and read English; and (3) had the cognitive ability to complete the questionnaire independently. Demographic data were also collected on the first visit.

Pilot Testing for Reading Level and Comprehension

The reading level of the draft instrument was assessed by CHOA's Learning Center and deemed appropriate for this age group. The OPTIMAL's confidence scale was administered as it had been originally published to 217 adolescents drawn from two pediatric clinics to gather feedback on the readability of the instrument by directly debriefing subjects after each administration to identify items which they did not understand. From these preliminary tests, it was learned that many of the adolescents in our test sample did not know the meaning of “stooping,” which had been used in OPTIMAL on one item (“bending/stooping”). Therefore this word was eliminated from the subsequent version of the instrument.

OPTIMAL measures self-confidence in movement in everyday (i.e., non-sports related) activities. Because adolescent athletes may not perceive a clear “boundary” between every-day life and their sports-related activities an explicit distinction was subsequently made about context in the instructions for study participants based on the questions they asked in filling out the AMCaMP (see Appendix for the full instrument). Subjects were instructed to think only of their non-sports-related activities.

Data Analysis

Descriptive statistics were calculated to assess the demographic and clinical characteristics of study participants. The entire sample was divided into a test sample and a validation sample (i.e., potential models were generated using half of the sample and then these models were evaluated in the half not used to generate them) to help guard against over-fitting sample-based error during the factor analyses. Exploratory factor analysis (EFA) was used to generate plausible hypothetical models which were then tested in the confirmatory factor analysis (CFA) phase. These analyses were used to understand: 1) how many constructs were assessed by the 22 items; and 2) which items were related to which constructs. Once a model which adequately explained the observed data was identified, a replication of that model in the validation sample was attempted to assess reproducibility of the results. As the data are categorical in nature (i.e., five-point Likert-type responses), polychoric correlation matrices were analyzed in both EFA and CFA. EFA model parameters were estimated using the CEFA software package. Ordinary least squares estimation in CEFA was used and, when applicable (i.e., when estimating models with more than one factor), an oblique CF-Quartimax rotation was employed. CFA model parameter estimates were obtained using Mplus. A mean- and variance-adjusted weighted least squares estimator (WLSMV) was used in Mplus.

Once the factor analyses were complete and a satisfactory latent structure was established, the newly formed scales were tested using standard psychometric methods from classical test theory including coefficient alpha, standard error of the measurement (SEM) calculated as

$$SEM = \hat{\alpha} \sqrt{1 - \hat{\sigma}^2},$$

where \(\hat{\sigma}\) is the estimated standard deviation for test scores and \(\hat{\alpha}\) is an estimate of the reliability (coefficient alpha, in our case), and minimal detectable change (MDC) calculated as

$$MDC = SEM \times 1.96 \sqrt{2}.$$

It is important to note that both SEM and MDC can also be calculated using repeated measures-type information, but that is not the route that pursued here. Also, it is important to remember that MDC is about detectable change, not necessarily important or meaningful change. There are suggested methods to address the meaningfulness of change, but they can be complex, involve variables outside the measure, and are beyond the scope of this project.
RESULTS

Sample
Demographic information on the sample is presented in Table 1. During the period of data collection, 1,115 adolescents with sports-related needs for rehabilitation were eligible for study. The population for this study was predominantly female, and 14.3 years old on average. The majority of participants were full-time students in middle and high school, who had been participating in sports for almost four years.

Of these 1,115 patients, 829 individuals had an initial examination. For factor analyses, only intake data were used. List-wise deletion (where any individual with a missing value is deleted) was used on the data before factor analyses were performed yielding a final sample of 661 subjects with complete data. This total sample was then split into a test sample and a validation sample (sample sizes of 331 and 330, respectively).

Exploratory Factor Analyses
Figure 1 displays a scree plot, which contains the eigenvalues associated with the sample polychoric correlation matrix computed using the test sample. There are a wide variety of “rules” governing interpretation of scree plots. Rather than using such information in a dogmatic fashion, the data from the scree plot was used to identify potentially viable solutions. One can often look for an “elbow” in a scree plot, which represents an inflection point after which the subsequent eigenvalues are all very similar. In order to keep the model as simple as viable, 1-, 2-, 3-, and 4-factor solutions were explored. For reasons of interpretation, the 3-factor model was preferred over the 1- or 2-factor model. Estimation of a fourth factor yielded a “walking” factor, which related primarily to the three items which reference walking. Although this extra covariance might have been worth modeling in some respects, the research team did not regard it as an interesting common factor.

Confirmatory Factor Analyses
In the CFA phase of analysis, a decision was made to test a 1-factor model, a 3-factor model with independent clustering (where each item relates to only the common factor it showed the strongest association with in the 3-factor EFA solution), a 3-factor model with cross-loadings (all of the loadings from the independent clustering model plus any additional loadings that were greater than 0.3 in abso-

Table 1. Study Population Demographics and Characteristics

<table>
<thead>
<tr>
<th>STUDY POPULATION</th>
<th>N=1,115</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>495</td>
</tr>
<tr>
<td>Female</td>
<td>620</td>
</tr>
<tr>
<td><strong>Mean Age (years)</strong></td>
<td>14.3</td>
</tr>
<tr>
<td><strong>School Grade</strong></td>
<td></td>
</tr>
<tr>
<td>Elementary (less than 6th)</td>
<td>22</td>
</tr>
<tr>
<td>Middle (6th through 8th)</td>
<td>256</td>
</tr>
<tr>
<td>High (9th through 12th)</td>
<td>381</td>
</tr>
<tr>
<td>Greater than 12th</td>
<td>11</td>
</tr>
<tr>
<td>Missing</td>
<td>445</td>
</tr>
<tr>
<td><strong>Average Years Sports Participation</strong></td>
<td>3.8</td>
</tr>
<tr>
<td><strong>Sport Played</strong></td>
<td></td>
</tr>
<tr>
<td>Basketball</td>
<td>120</td>
</tr>
<tr>
<td>Soccer</td>
<td>113</td>
</tr>
<tr>
<td>Football</td>
<td>103</td>
</tr>
<tr>
<td>Baseball</td>
<td>97</td>
</tr>
<tr>
<td>Other</td>
<td>227</td>
</tr>
<tr>
<td>Missing</td>
<td>455</td>
</tr>
</tbody>
</table>
The 90% confidence intervals around the RMSEA values were overlapping. Adding the three additional parameters identified by Mplus as having the largest corresponding MIs did significantly improve the model fit (RMSEA = 0.08, TLI = 0.98).

Cross-validation
Three models (3FIC, 3FIC-W, and 3FIC-MI) were explored in the validation sample to evaluate the extent to which these models fit a (relatively) new data set as well as the test sample. As the test and validation samples were chosen at random from the original sample, differences in the fit of these models help us understand sampling variability and avoid over-fitting models to sample-specific error. These results are also summarized in Table 2, where the models have the same name with a new “V” prefix to identify those results as coming from fitting a model in the validation sample. All three models showed slightly better fit in the validation sample. This is an encouraging result which suggests that over-modeling sampling error in the original sample did not occur.

The 1-factor model fit poorly (RMSEA = 0.19, TLI = 0.86), which is consistent with the EFA results. The 3-factor model with independent clustering (3FIC) fit the data significantly better (RMSEA = 0.11, TLI = 0.96). Although the TLI value was acceptable, the RMSEA value was on the border of values usually considered representative of acceptable model fit. Allowing additional parameters to be estimated in 3FCL and 3FIC-W improved model fit slightly, but

Figure 1. Scree Plot for the 22-item Core Set.
When considered in their totality, these results led to the conclusion that there were three common factors being measured by the 22 items in the core set. The first factor reflects the trunk (items 1-4, 7), one reflects the lower extremities (items 5, 6, 8-16), and the third comprises items concerning the upper extremities (17-22). Therefore, we calculated point estimates and standard errors for the 3FIC model using the full combined sample, which are presented in Table 3, were calculated.

**Reliability Analyses**

Once a satisfactory factor structure was identified, about a goal was set to provide additional evidence about the reliability of the resulting scores, including assessment of coefficient alpha, SEM, and MDC. Based on the factor analyses, three scores for each subject were constructed and the resulting reliability properties were evaluated. Table 4 contains the summary information about each of the three scales.

**Score Reporting**

All study subjects were offered the opportunity to comment verbally to administering clinicians on the interpretability of the instrument. Most subjects did not comment, but among those comments shared verbally by clinicians with the research team, a consistent theme that the scoring system seemed counter-intuitive was noted. Following the originally published scoring of OPTIMAL, the responses for each item were displayed left to right from “fully confident” to “not at all confident” using the same arbitrary value assignment of 1-5 arrayed left to right. In this scheme, a high or “best” score on, say, the trunk subscale was five while 25 was actually a low or “worst” score possible. Not surprisingly, adolescents found this scoring confusing. Therefore, the values assigned to each level of response was reversed so that higher numbers represented greater confidence. To ease interpretation further, the score was calculated as a percentage of the available points achieved. Because the subjects in this study were also students who were used to being graded academically, they grasped the difference between scoring 0% and 100% on an assessment without any difficulty. This allows scores for the three scales, which have different lengths, to be expressed in a comparable metric. This ease of interpretation held true for cases with missing values where the ratio was calculated as the total actual points awarded across all items answered (minus the minimum possible score) divided by the total possible points achievable across all items answered (minus the minimum possible score), multiplied by 100%.

**DISCUSSION**

On a very large sample drawn from multiple sites, the data indicate that the AMCaMP separated itself into three factors: lower body, upper body, and core, and performed adequately when subjected to classic psy-
### Table 3. CFA Point Estimates and Standard Errors from Preferred Model (3FIC)

<table>
<thead>
<tr>
<th>Item</th>
<th>Content</th>
<th>Trunk</th>
<th>Lower Extremities</th>
<th>Upper Extremities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lying Flat</td>
<td>0.82</td>
<td>(0.04)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Rolling Over</td>
<td>0.86</td>
<td>(0.04)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Moving - Lying to Sitting</td>
<td>0.88</td>
<td>(0.03)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Sitting</td>
<td>0.74</td>
<td>(0.03)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Standing</td>
<td></td>
<td>0.81 (0.03)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Squatting</td>
<td></td>
<td>0.84 (0.02)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Bending Over</td>
<td></td>
<td>0.87 (0.03)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Balancing</td>
<td></td>
<td>0.69 (0.03)</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Kneeling</td>
<td></td>
<td>0.74 (0.03)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Walking - Short Distance</td>
<td></td>
<td>0.93 (0.02)</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Walking - Long Distance</td>
<td></td>
<td>0.89 (0.02)</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Walking - Outdoors</td>
<td></td>
<td>0.91 (0.02)</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Climbing Stairs</td>
<td></td>
<td>0.85 (0.02)</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Hopping</td>
<td></td>
<td>0.97 (0.01)</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Jumping</td>
<td></td>
<td>0.97 (0.01)</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Running</td>
<td></td>
<td>0.82 (0.02)</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Pushing</td>
<td></td>
<td>0.95 (0.01)</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Pulling</td>
<td></td>
<td>0.94 (0.01)</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Reaching</td>
<td></td>
<td>0.86 (0.02)</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Grasping</td>
<td></td>
<td>0.86 (0.03)</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Lifting</td>
<td></td>
<td>0.90 (0.01)</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Carrying</td>
<td></td>
<td>0.93 (0.02)</td>
<td></td>
</tr>
</tbody>
</table>

*Note. Correlation between Trunk and Lower Extremities was 0.71 (0.04), between Trunk and Upper Extremities was 0.64 (0.04), and between Lower Extremities and Upper Extremities was 0.38 (0.05). In table and note point estimates for 3FIC model are presented followed by estimated standard error in parentheses.*

### Table 4. Classical Test Theory Results

<table>
<thead>
<tr>
<th>Scale</th>
<th>Items</th>
<th># of Items</th>
<th>Raw Mean</th>
<th>Raw SD</th>
<th>Raw Min</th>
<th>Raw Max</th>
<th>Scaled Mean</th>
<th>Scaled SD</th>
<th>Alpha</th>
<th>SEM&lt;sup&gt;a&lt;/sup&gt;</th>
<th>MDC&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk</td>
<td>1-4, 7</td>
<td>5</td>
<td>7.01</td>
<td>3.29</td>
<td>5</td>
<td>25</td>
<td>10%</td>
<td>16.4%</td>
<td>0.82</td>
<td>1.38</td>
<td>3.83</td>
</tr>
<tr>
<td>Lower Body</td>
<td>5,6-8, 16</td>
<td>11</td>
<td>21.96</td>
<td>10.83</td>
<td>11</td>
<td>55</td>
<td>24.9%</td>
<td>24.6%</td>
<td>0.94</td>
<td>2.74</td>
<td>7.6</td>
</tr>
<tr>
<td>Upper Body</td>
<td>17-22</td>
<td>6</td>
<td>10.7</td>
<td>5.68</td>
<td>6</td>
<td>30</td>
<td>19.5%</td>
<td>23.7%</td>
<td>0.91</td>
<td>1.68</td>
<td>4.65</td>
</tr>
</tbody>
</table>

<sup>a</sup>Standard Error of Measurement is calculated as $SEM = sd\sqrt{1 - r}$, where $sd$ is the sample standard deviation and $r$ is the sample estimate of coefficient alpha.

<sup>b</sup>Minimum Detectable Change (MDC) is calculated as $MDC = SEM * 1.96 * \sqrt{2}$.

<sup>c</sup>Raw descriptives include reverse coding, but no change to percentile.
chometric testing. All three subscales demonstrated good internal consistency and an MDC threshold which is reasonable for clinical practice and documentation of clinical progress and outcomes. As was the case with OPTIMAL, its progenitor instrument, AMCaMP items reflecting the neuromusculoskeletal core do not lend themselves to a scale that is quite as unidimensional as the scales for either the upper or lower body. From the perspective of clinicians for whom movement is the primary phenomenon of interest, this finding is clinically axiomatic. While the focus on intervention may be primarily directed at segmental or intersegmental movement, each factor must make its full contribution to the overall whole body movement or action. Limb mobility must combine successfully with trunk stability to produce sustainable movement or action that is safe, effective, and efficient. Thus an instrument which captures these three factors has great potential to document sources of variability in movement-related outcomes.

Beyond its value as a psychometrically acceptable instrument, AMCaMP possesses two distinct attributes. The first is its patient-centricity. By measuring confidence in movement as a critical outcome of rehabilitation, this instrument can describe the impact of injury or illness on movement from the patient’s point of view. Furthermore, because self-efficacy is highly predictive of what a person might actually do once leaving clinical care, it may serve as a proxy measure of carry-over in proper movement after returning to sport.

On a methodological note, although the 3FIC-MI model was superior when evaluated using the proposed model fit criteria, there are no substantively different conclusions one would reach in accepting this model over the simpler a priori 3FIC model. As it has been proposed to score these scales using summed scores, the additional parameters, while improving model fit, will not impact any conclusions that are likely to be made. However, if one were to use factor scores in the future (or a unidimensional item response theory analysis), the correlated residuals that were identified here may prove to be strong enough to require attention.

While self-report instruments can provide a necessary patient-centric perspective, it is not in itself a sufficient basis for sound clinical judgment and treatment planning by health professionals. A parallel set of instruments for assessing functional performance objectively should be used to complement the data provided by AMCaMP. Capturing both perspectives should lead to patient-centric goal-setting, professionally competent treatment planning, and outcomes relevant to all stakeholders. Future research should also explore the predictive validity of AMCaMP, especially with respect to recurrent injury.

**SUMMARY**

Primarily relying on factor analysis, the latent structure of AMCaMP was established. This 22-item self-report instrument measuring confidence in performing particular movements or actions revealed a three factor structure comprising the trunk, upper body and lower body. These three scales demonstrated good internal consistency and an acceptable MDC. These psychometric properties and the instrument’s patient-centricity and ability to provide an ecological context for a respondent’s answers recommend its use for adolescent athletes, especially when self-efficacy regarding confidence in movement in daily activities prior to returning to sport is a primary clinical or research outcome.

**REFERENCES**


Confidence-Evaluation

Name: ___________________________ Date: ______________________

Date of Birth: ___________ Gender (circle one): Male Female

Grade in school: _______ Years participating in current sport(s): _______

How CONFIDENT are you about completing these activities?

These are questions about how well you believe you can complete each of the following activities. Please respond to each question while thinking about your non-sports activities.

Please circle the number that matches your answer for each activity listed.

<table>
<thead>
<tr>
<th>Staff Use Only</th>
<th>Fully confident in my ability to complete</th>
<th>Very confident</th>
<th>Moderately confident</th>
<th>Somewhat confident</th>
<th>Not confident in my ability to complete</th>
<th>Does not apply to me</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID #</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Lying flat</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>2. Rolling over</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>3. Moving–lying to sitting</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>4. Sitting</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>5. Standing</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>6. Squatting</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>7. Bending over</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>8. Balancing</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>9. Kneeling</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>10. Walking–short distance</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>11. Walking–long distance</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>12. Walking–outdoors</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>13. Climbing stairs</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>14. Hopping</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>15. Jumping</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>16. Running</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>17. Pushing</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>18. Pulling</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>19. Reaching</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>20. Grasping</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>21. Lifting</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>22. Carrying</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
</tbody>
</table>

23. Given the things you have problems with in the list above, which 3 would you like to complete with more confidence? (for example, if you would most like to be able to climb stairs, kneel, and hop with complete confidence, you would choose: (1. 13 2. 14 3. 14) 1. ____ 2. ____ 3. ____
ABSTRACT

Background: While advanced diagnostic imaging is a large contributor to the growth in health care costs, direct-access to physical therapy is associated with decreased rates of diagnostic imaging. No study has systematically evaluated with evidence-based criteria the appropriateness of advanced diagnostic imaging, including magnetic resonance imaging (MRI), when ordered by physical therapists. The primary purpose of this study was to describe the appropriateness of magnetic resonance imaging (MRI) or magnetic resonance arthrogram (MRA) exams ordered by physical therapists in a direct-access sports physical therapy clinic.

Study Design: Retrospective observational study of practice.

Hypothesis: Greater than 80% of advanced diagnostic imaging orders would have an American College of Radiology (ACR) Appropriateness Criteria rating of greater than 6, indicating an imaging order that is usually appropriate.

Methods: A 2-year retrospective analysis identified 108 MRI/MRA examination orders from four physical therapists. A board-certified radiologist determined the appropriateness of each order based on ACR appropriateness criteria. The principal investigator and co-investigator radiologist assessed agreement between the clinical diagnosis and MRI/surgical findings.

Results: Knee (31%) and shoulder (25%) injuries were the most common. Overall, 55% of injuries were acute. The mean ACR rating was 7.7; scores from six to nine have been considered appropriate orders and higher ratings are better. The percentage of orders complying with ACR appropriateness criteria was 83.2%. Physical therapist's clinical diagnosis was confirmed by MRI/MRA findings in 64.8% of cases and was confirmed by surgical findings in 90% of cases.

Conclusions: Physical therapists providing musculoskeletal primary care in a direct-access sports physical therapy clinic appropriately ordered advanced diagnostic imaging in over 80% of cases. Future research should prospectively compare physical therapist appropriateness and utilization to other groups of providers and explore the effects of physical therapist imaging privileging on outcomes.

Level of Evidence: Diagnosis, Level 3

Keywords: Diagnostic imaging, direct access, sports physical therapy
INTRODUCTION

Direct access to physical therapy evaluation and intervention has the potential to reduce costs and improve outcomes in musculoskeletal medicine. The results of multiple studies show that direct access to physical therapy is associated with improved patient outcomes and decreased costs, with minimal risk of harm to the patient.1–6 The diagnostic accuracy of a physical therapist’s clinical examination has been shown to be the equivalent of orthopedic surgeons and well above non-orthopedic providers when compared to an MRI diagnosis.3 Although more research on harm is needed, in a large cohort of over 50,000 patients in the U.S. military, no adverse events related to inappropriate patient management were reported by those who sought physical therapy services without a physician referral.4 Additionally, numerous case reports describe the appropriate identification of patients whose pathology lies outside the scope of physical therapy by physical therapists operating in a direct-access setting.1,6

Advanced diagnostic imaging, which includes magnetic resonance imaging (MRI), computed tomography, and nuclear medicine imaging, is a large contributor to growth in health care spending in the United States. National expenditures on all medical imaging were approaching $100 billion in 2006, although the rate of growth is beginning to slow.7,8 A high percentage of advanced imaging ordered by physicians in primary care clinics does not meet evidence-based appropriateness criteria.7,9,10 In a review of over 500 advanced imaging orders by primary care physicians, 26% were considered inappropriate by physician reviewers using a computerized commercial evidence-based appropriateness system.7 In a pre-authorization center using the American College of Radiology (ACR) Appropriateness Criteria, 15% of magnetic resonance imaging (MRI) examinations requests were considered inappropriate.9 Overutilization of diagnostic imaging is, at best, associated with no effect on outcomes;11–13 and in conditions of the spine, there is evidence to suggest that early utilization of diagnostic imaging may produce poorer outcomes with increased cost.12–15

Direct-access to physical therapy is associated with decreased rates of diagnostic imaging.5 However, only four studies (only one of which was conducted in the U.S.) reported on the rate of diagnostic imaging.16–19 It is unclear from the results of three of those studies whether the ordering provider was a physical therapist or physician.17–19 A large portion of the research on cost effectiveness, efficiency, and clinical outcomes related to imaging utilization has examined advanced practice physical therapists (outside the U.S.) in an orthopedic screening role. Advanced practice physical therapists who screen patients referred to an outpatient orthopaedic surgery practice, are less likely to order radiographs and have lower costs associated with the care of non-surgical conditions when compared with orthopedic surgeons.20–22

The majority of physical therapists in the U.S. military provide some degree of direct-access musculoskeletal care and possess privileges to order both radiographs and advanced diagnostic imaging. All of the military services have physical therapists working in capacities that could be described as “primary care providers” for musculoskeletal care. These include providers in small outpatient medical clinics, within special operations communities, and during deployment to theaters of war. The United States Military Academy at West Point provides a setting to study this unique combination of clinical privileges.

The patient population is relatively homogenous; the majority of patients are cadets between the ages of 18-24. In 2013-2014, 1,303 patients were evaluated at the Cadet Sports Physical Therapy Clinic. Many musculoskeletal injuries incurred by cadets are initially evaluated by physical therapists, either on the field during sports coverage or during walk-in musculoskeletal clinic hours. Rarely are cadets evaluated by primary care providers for musculoskeletal injuries.

No study has systematically evaluated with evidence-based criteria the appropriateness of advanced diagnostic imaging ordered by physical therapists in a direct-access clinic. The primary purpose of this study was to describe the appropriateness of magnetic resonance imaging (MRI) or magnetic resonance arthrogram (MRA) exams ordered by physical therapists in a direct-access sports physical therapy clinic. Secondary purposes were to describe the utilization rates of diagnostic imaging, describe the diagnostic accuracy of the physical therapist’s clinical
graduates. Clinical practice experience ranged from 1 to 20 years. All physical therapists possessed the same clinical privileges, no constraints had been placed on their ability to order any imaging modality, and they were unaware that their practice patterns were being evaluated. The majority of patients were young males (77%) and the majority of injuries were acute (55%). The demographics of the providers and patients in the study are presented in Tables 1 and 2. The study protocol was approved by the Institutional Review Board at Keller Army Community Hospital, West Point, New York (Protocol #15-024).

examination compared to MRI findings and, if applicable, surgical findings, and to compare utilization, appropriateness, and diagnostic accuracy between board certified physical therapists and non-board certified physical therapists. It was hypothesized that:

1. Greater than 80% of advanced diagnostic imaging orders will comply with American College of Radiology (ACR) Appropriateness Criteria (ACR rating > 6).

2. All physical therapists will utilize radiographs and advanced diagnostic imaging at rates equal to or lower than those previously reported for primary care physicians.

3. Agreement between the clinical examination diagnosis and the MRI/surgical diagnosis will be greater than 75%.

4. Board certified physical therapists will utilize diagnostic imaging at lower rates and with increased appropriateness based on ACR criteria.

**METHODS**

This was a single-center retrospective cohort study that took place at United States Military Academy at West Point. The patient population consisted of over 4,500 Cadets, faculty, staff, and family members who live and work at West Point. Four physical therapists were included in this study; three were board certified and were post-professional residency/fellowship graduates. Clinical practice experience ranged from 1 to 20 years. All physical therapists possessed the same clinical privileges, no constraints had been placed on their ability to order any imaging modality, and they were unaware that their practice patterns were being evaluated. The majority of patients were young males (77%) and the majority of injuries were acute (55%). The demographics of the providers and patients in the study are presented in Tables 1 and 2. The study protocol was approved by the Institutional Review Board at Keller Army Community Hospital, West Point, New York (Protocol #15-024).

<table>
<thead>
<tr>
<th>Table 1. Characteristics of the providers participating in the study</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PT #1</strong></td>
</tr>
<tr>
<td>Years of experience</td>
</tr>
<tr>
<td>Board certification</td>
</tr>
<tr>
<td>Residency/Fellowship</td>
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<tr>
<td>Formal imaging training (instruction hours)</td>
</tr>
</tbody>
</table>

PT= physical therapist; OCS= orthopedic certified specialist; SCS= sports certified specialist.

<table>
<thead>
<tr>
<th>Table 2. Patient demographics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Patient Characteristics</strong></td>
</tr>
<tr>
<td>Age</td>
</tr>
<tr>
<td>Sex</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Acuity</td>
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</tbody>
</table>

SD= standard deviation.
The radiology picture archive and communication system (PACS) was searched for the two-year period between January 2013 to December 2014. One-hundred eight MRI or MRA examinations ordered by physical therapists practicing in a direct-access sports physical therapy clinic were identified. The total number of conventional radiograph orders and MRI/MRA orders were counted for each provider. For each patient with an MRI/MRA ordered by a physical therapist during that period, the electronic medical record (EMR) was reviewed and documentation from physical therapy encounters and radiology exams were extracted and de-identified.

Each de-identified case file was provided to a board-certified radiologist who determined the appropriateness of each MRI/MRA examination order based on ACR Appropriateness Criteria. The ACR Appropriateness Criteria are evidence-based guidelines developed to assist referring physicians and other providers with making the most appropriate imaging decision for a specific clinical condition. Utilizing these guidelines may enhance quality of care and contribute to more efficient use of diagnostic imaging. For each clinical condition, an ACR rating describes the level of appropriateness for each imaging study. The ACR rating scale ranges from 1-9. Scores of 7 and above indicate usually appropriate, scores of 4-6 indicate that the test may be appropriate, and scores of 3 or less indicate that the tests are usually not appropriate. For the purposes of this study, scores of 7 or greater operationally defined as “appropriate” and scores of 6 or less were operationally defined as “inappropriate.” A modified example of the ACR appropriateness criteria for the evaluation of acute knee injuries is shown in Appendix 1.

The principal investigator physical therapist and co-investigator radiologist assessed agreement between the referring provider's clinical examination diagnosis and the MRI. The principal investigator thoroughly reviewed the patient’s operative report to assess agreement between the clinical diagnosis and surgical findings. The provider's imaging order and clinical documentation were used to establish the clinical diagnosis. If the provider's clinical diagnosis did not match anything within the radiologist's report, or if the report was determined to be normal, the provider was not given credit for clinical diagnostic accuracy. When assessing agreement with MRI, a provider was given a great deal of latitude within their clinical diagnosis. For example, if the provider's clinical diagnosis was anterior shoulder instability and the MRI report noted an anterior-inferior glenoid labrum tear, then the provider was given credit for agreement. Additionally, in cases of multiple pathological findings on the MRI, a clinical diagnosis was considered accurate if any diagnosis within the assessment or radiology report matched. For example, if the MRI report described an ACL tear with a lateral meniscus tear, a provider was given credit for agreement if a diagnosis of an ACL tear or lateral meniscus tear was present.

Data analysis was performed using R version 3.1.3 and R Commander version 2.1-7. Chi-square tests were used to compare ACR compliance and clinical diagnostic accuracy between the three board certified and one non-board certified physical therapists. Odds ratios were calculated when chi-squared analyses were significant at the alpha=0.05 level.

RESULTS

For the two-year study period, 1303 new patients were evaluated with 3562 total patient visits, resulting in orders for 521 radiographs and 108 MRI/MRA examinations. The overall utilization of diagnostic imaging is presented in Table 3.

The majority of the 108 MRI/MRA examination orders were for knee (31%) or shoulder (25%) injuries. The breakdown of the MRI/MRA examination orders by body region is shown in Figure 1. Physical therapists evaluated/re-evaluated patients for a mean of three visits prior to ordering MRI examinations. Radiographs were frequently ordered for injuries to the foot/ankle (21.1%), wrist/hand (18.8%), shoulder (16.9%), and knee (13.8%). The breakdown of the radiograph orders by body region is shown in Figure 2.

The mean ACR rating for advanced diagnostic imaging orders was 7.7 and the percentage of orders complying with the ACR criteria (rating ≥ 7) was 83.2%. Seven MRI/MRA orders could not be categorized within the ACR criteria because no criteria existed for their condition. Table 4 shows the ACR compliance across all physical therapists. There was not a
significant association between ACR compliance and board certification ($X^2 = 0.43, p = 0.51$) (Figure 3).

Physical therapist’s clinical diagnosis agreed with the MRI/MRA findings in 64.8% of cases and agreed with surgical findings in 90% of cases (Table 5). There was a significant association between board certification and clinical diagnostic accuracy ($X^2 = 6.86, p = 0.008$). Board certified physical therapists were 3.03 (95% CI 1.3, 7.08) times more likely to have docu-

![Figure 1. Advanced imaging (MRI/MRA) by body region. L-S= lumbar spine; C-S= cervical spine.](image1)

![Figure 2. Radiographs by body region. L-S= lumbar spine; C-S= cervical spine; TS= thoracic spine.](image2)

mented the correct clinical diagnosis (based on MRI/ MRA examination findings) than the non-board certified physical therapist (Table 6, Figure 3).

**DISCUSSION**

The primary purpose of this study was to describe the appropriateness and utilization of advanced diagnostic imaging by physical therapists in a direct-access sports physical therapy clinic. This is the first study to describe the appropriateness, systematically

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**Table 3. Overall utilization of diagnostic imaging**

<table>
<thead>
<tr>
<th></th>
<th>OVERALL</th>
<th>PT #1</th>
<th>PT #2</th>
<th>PT #3</th>
<th>PT #4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RADIOGRAPHS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-year overall utilization [per new patient evaluation]</td>
<td>40.0% (521/1303)</td>
<td>33.6% (94/280)</td>
<td>40.1% (184/459)</td>
<td>37.8% (137/362)</td>
<td>52.5% (106/202)</td>
</tr>
<tr>
<td><strong>MRI/MRA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-year overall utilization [per new patient evaluation]</td>
<td>8.3% (108/1303)</td>
<td>7.5% (21/280)</td>
<td>7.4% (34/459)</td>
<td>11.9% (43/362)</td>
<td>5.0% (10/202)</td>
</tr>
<tr>
<td><strong>RADIOGRAPHS</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2-year overall utilization [per total # patient visits]</td>
<td>14.6% (521/3562)</td>
<td>12.7% (94/739)</td>
<td>13.6% (184/1353)</td>
<td>13.3% (137/1029)</td>
<td>24.0% (106/441)</td>
</tr>
<tr>
<td><strong>MRI/MRA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-year overall utilization [per total # patient visits]</td>
<td>3.0% (108/3562)</td>
<td>2.8% (21/739)</td>
<td>2.5% (34/1353)</td>
<td>4.2% (43/1029)</td>
<td>2.3% (10/441)</td>
</tr>
</tbody>
</table>

A “new patient evaluation” refers to the only the initial evaluation of the patient for the condition. PT= physical therapist; MRI= magnetic resonance imaging; MRA= magnetic resonance arthrogram; #= number
surgical findings in 90% of cases (Table 5). There was a significant association between board certification and clinical diagnostic accuracy ($X^2 = 6.86, p = 0.008$). Board certified physical therapists were 3.03 (95% CI 1.3, 7.08) times more likely to have documented the correct clinical diagnosis (based on MRI/MRA examination findings) than the non-board certified physical therapist (Table 6, Figure 3).

**DISCUSSION**

The primary purpose of this study was to describe the appropriateness and utilization of advanced diagnostic imaging by physical therapists in a direct-access sports physical therapy clinic. This is the first study to describe the appropriateness, systematically evaluated with evidence-based criteria, and the utilization of advanced diagnostic imaging ordered by physical therapists in a direct-access setting. In over 80% of cases, a board-certified radiologist considered physical therapist MRI/MRA orders appropriate by ACR criteria. Based on imaging rates published in

**Table 4. Appropriate*ness of advanced diagnostic imaging [MRI/MRA]**

<table>
<thead>
<tr>
<th></th>
<th>OVERALL</th>
<th>PT #1</th>
<th>PT #2</th>
<th>PT #3</th>
<th>PT #4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (SD) ACR rating</td>
<td>7.7 (2.5)</td>
<td>8.3 (1.1)</td>
<td>7.6 (2.7)</td>
<td>7.7 (2.7)</td>
<td>7.0 (1.8)</td>
</tr>
<tr>
<td>ACR compliance (rating ≥ 7)</td>
<td>83.2% (84/101)</td>
<td>90.0% (18/20)</td>
<td>79.3% (23/29)</td>
<td>83.7% (36/43)</td>
<td>77.8% (7/9)</td>
</tr>
<tr>
<td>Mean (SD) visits prior to MRI/MRA</td>
<td>3.0 (2.2)</td>
<td>3.1 (2.7)</td>
<td>2.8 (2.6)</td>
<td>3.1 (1.8)</td>
<td>2.6 (3.2)</td>
</tr>
</tbody>
</table>

PT= physical therapist; ACR= American College of Radiology; MRI= magnetic resonance imaging; MRA= magnetic resonance arthrogram.

**Table 5. Diagnostic accuracy of the clinical exam**

<table>
<thead>
<tr>
<th></th>
<th>OVERALL</th>
<th>PT #1</th>
<th>PT #2</th>
<th>PT #3</th>
<th>PT #4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagnostic accuracy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clinical exam vs MRI</td>
<td>64.8% (70/108)</td>
<td>85.7% (18/21)</td>
<td>47.1% (16/34)</td>
<td>72.1% (31/43)</td>
<td>50% (5/10)</td>
</tr>
<tr>
<td>Diagnostic accuracy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clinical exam vs Surgery</td>
<td>90.0% (18/20)</td>
<td>80% (4/5)</td>
<td>83.3% (5/6)</td>
<td>100% (8/8)</td>
<td>100% (1/1)</td>
</tr>
</tbody>
</table>

While every patient had an MRI prior to surgery; only 20% of patients with an MRI eventually had surgery.

PT= physical therapist; MRI= magnetic resonance imaging.

**Figure 3. Appropriateness of advanced diagnostic imaging and accuracy of the clinical exam in three board certified PTs versus a single non-board certified PT, expressed as a percentage of cases evaluated. ACR- American College of Radiology, Dx- diagnostic, MR- magnetic resonance imaging**

significant association between ACR compliance and board certification ($X^2 = 0.43, p = 0.51$) (Figure 3).

Physical therapist's clinical diagnosis agreed with the MRI/MRA findings in 64.8% of cases and agreed with
The setting of care must be taken into account when analyzing prior research on the rates of imaging orders. The most similar study to this one examined the use of physical therapists operating in an emergency department in Australia. Physical therapists ordered radiographs on 54% of patients with musculoskeletal injuries (excluding high-risk trauma, open fractures, multiple comorbidities, evidence of drug-seeking behavior, and altered consciousness). Physical therapists managed 47% of patients independently; 84% of injuries involved the upper or lower extremity. The physical therapists in this study ordered radiographs less frequently and the body region distribution of injuries was similar (88% involving the extremities).

In two studies of physical therapists operating in a direct-access setting in the United Kingdom, 5-7% of patients were referred for imaging. Of those patients, 35-54% were evaluated for lumbar or cervical spine disorders of unknown chronicity. While it appears that the physical therapists in the current study ordered imaging at much higher rates (40% radiographs, 8% MRI/MRA), the sample in this study appears different as patients were evaluated primarily for extremity disorders (88%), more than half of which were acute injuries.

Physical therapists screening patients referred to orthopedic surgery clinics ordered imaging at a rate of 14% for radiographs and 27% for MRI. These patients were older (mean age 48) than the patients described in this study and were already screened by a primary care provider, potentially lessening the need for additional imaging. Additionally, another study did not examine the appropriateness of the radiographs ordered by this sample of physical therapists. When examining the ACR criteria, Levy et al reported that 50-60% of MRI requests received at a pre-authorization center were appropriate (rating > 7). Petron et al reported that only 12% of MRI orders for chronic knee pain would have been ordered by orthopedic surgeons who retrospectively reviewed the case files. In this study of physical therapists evaluating musculoskeletal injuries in a direct-access setting, 83% of all MRI/MRA orders were considered appropriate, exceeding the highest previously reported level of 74% by Lehnert et al.

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This study did not examine the appropriateness of the radiographs ordered by this sample of physical therapists. When examining the ACR criteria, the only body region where radiographs ordered during the initial evaluation do not have a rating of 9 is the lumbar spine. In this study, only 18 of the 521 (3.5%) radiograph orders were for the lumbar spine. Additionally, it would not be feasible for an independent radiologist to determine appropriateness for over 500 orders. In the future, electronic health care databases may be able to provide information regarding the appropriateness of radiographs ordered by physical therapists.

| Table 6. Association of board certification with accurate clinical diagnosis |
|---------------------------------|-----------------|-----------------|
|                                 | Accurate Diagnosis | Inaccurate Diagnosis |
| Board certified PT             | 54              | 20              |
| Non-board certified PT         | 16              | 18              |
| Board certified physical therapists were 3.03 times more likely to arrive at a diagnosis that matched the MRI diagnosis than the non-board certified physical therapist. $X^2 = 5.77, p = 0.008$ PT= physical therapist; MRI= magnetic resonance imaging |
The results of the current study are similar to previous work by Moore et al, performed at the same facility, describing the clinical diagnostic accuracy of physical therapists. In that study, the overall clinical diagnostic accuracy was 75%, the accuracy of three board certified physical therapists was 86%, and the accuracy of two non-board certified physical therapists was 50%. The overall accuracy of the physical therapists in this study was slightly lower (65%), while the accuracy of the non-board certified physical therapist was similar (47%). While the physical therapists in both studies were all in the military, there was a variety of entry-level and post-professional training. The two board certified physical therapists in the study by Moore et al had a mean of 10.5 years of clinical experience, while the non-board certified physical therapist in this study had only one year of clinical experience. While the rates of diagnostic accuracy were similar between these two small samples of non-board certified physical therapists, the contribution of clinical experience versus board certification is not able to be determined.

There are several limitations to this study. The sample of physical therapists was small; only one non-board certified physical therapist with one year of clinical experience was included. The three board certified physical therapists had a mean of 11 years of clinical experience, many of which were in a direct-access setting. While there were no significant differences in ACR compliance between the board certified and non-board certified providers, there was a statistically significant difference in clinical diagnostic accuracy. Entry-level training may be sufficient to allow physical therapists to order diagnostic imaging appropriately. It is not known if the difference in clinical diagnostic accuracy was due to differences in clinical experience, formal imaging training, residency/fellowship training or board certification. A larger sample of physical therapists is needed to fully examine the effects of clinical experience and post-professional training on diagnostic accuracy.

A retrospective study can be a design limitation; however, it may have added credibility by reducing provider bias associated with the Hawthorne effect. The use of MRI as the main reference standard for clinical diagnostic accuracy is a limitation. However, utilization of surgery as a reference standard would not be feasible as only 20% of diagnostic imaging orders eventually required surgery. Additionally, ACR criteria are not available for every diagnosis and/or clinical presentation. The radiologist examining the case files determined either the most appropriate criteria to use or whether the case did not fit any existing criteria.

Future research should utilize a larger sample with a large range of clinical experience and attempt to directly compare the appropriateness and utilization of physical therapists and other providers operating in similar patient care settings. A retrospective design is likely needed given the strong possibility of the Hawthorne effect with this type of research if the providers are aware that their clinical practice pattern is being observed. A multi-center study may further investigate the effects of clinical experience, formal imaging training, residency/fellowship training, and board certification on clinical diagnostic accuracy. Examination of physical therapists with similar clinical experience who are and are not board certified may better inform the impact of board certification. Finally, future studies should examine the effect of physical therapist imaging on outcomes, such as exploring if the early utilization of imaging impacts the risk for surgical intervention or influences outcomes.

CONCLUSION

Physical therapists operating as musculoskeletal primary care providers in a direct-access sports physical therapy clinic appropriately ordered advanced diagnostic imaging in over 80% of cases. They ordered MRI/MRA in only 8% of all new evaluations, suggesting judicious use of advanced imaging. Future research should prospectively compare physical therapist appropriateness and utilization of diagnostic imaging to other groups of providers and explore the effects of physical therapist imaging privileges on outcomes.
REFERENCES


Appendix

Modified Example of ACR Appropriateness Criteria for Acute Trauma to the Knee

Legend:
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate.
Relative Radiation Level (RRL): 🅿️, Adult effective dose estimate range < 0.1 mSv; 🅿️adenMOVE, Adult effective dose estimate range 0.1-1.0 mSv.

Variant 1: Patient any age (excluding infants) who sustains a fall or twisting injury. Physical exam demonstrates no focal tenderness and no effusion. The patient is able to walk. First study.

<table>
<thead>
<tr>
<th>Radiologic Procedure</th>
<th>Rating</th>
<th>Relative Radiation Level (RRL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee X-ray</td>
<td>2</td>
<td>🅿️adenMOVE</td>
</tr>
<tr>
<td>MRI without contrast</td>
<td>2</td>
<td>None</td>
</tr>
<tr>
<td>MRI/MRA knee with and without contrast</td>
<td>1</td>
<td>None</td>
</tr>
<tr>
<td>CT knee without contrast</td>
<td>1</td>
<td>🅿️adenMOVE</td>
</tr>
<tr>
<td>Ultrasound knee</td>
<td>1</td>
<td>None</td>
</tr>
</tbody>
</table>

Variant 2: Patient any age (excluding infants) who sustains a fall or twisting injury. Physical exam demonstrates one or more of the following: focal tenderness, effusion, or inability to bear weight. First study.

<table>
<thead>
<tr>
<th>Radiologic Procedure</th>
<th>Rating</th>
<th>Relative Radiation Level (RRL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee X-ray</td>
<td>9</td>
<td>🅿️adenMOVE</td>
</tr>
<tr>
<td>MRI knee without contrast</td>
<td>5</td>
<td>None</td>
</tr>
<tr>
<td>Ultrasound knee</td>
<td>2</td>
<td>None</td>
</tr>
<tr>
<td>CT knee without contrast</td>
<td>2</td>
<td>🅿️adenMOVE</td>
</tr>
<tr>
<td>MRI/MRA knee with and without contrast</td>
<td>1</td>
<td>None</td>
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</table>

Variant 3: Patient any age (excluding infants) who sustains a fall or twisting injury with either no fracture or a Segond fracture seen on radiographs. Physical exam demonstrates one or more of the following: focal tenderness, effusion, or inability to bear weight. Next study.

<table>
<thead>
<tr>
<th>Radiologic Procedure</th>
<th>Rating</th>
<th>Relative Radiation Level (RRL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRI knee without contrast</td>
<td>9</td>
<td>None</td>
</tr>
<tr>
<td>CT knee without contrast</td>
<td>5</td>
<td>🅿️adenMOVE</td>
</tr>
<tr>
<td>MRI knee with and without contrast</td>
<td>1</td>
<td>None</td>
</tr>
<tr>
<td>Ultrasound knee</td>
<td>1</td>
<td>None</td>
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ABSTRACT

Background: Although it is believed that trunk function is important for athletic performance, few researchers have demonstrated a significant relationship between the trunk function and athletic performance. Recently, the prone plank and side plank tests have been used to assess trunk function.

Purpose: The purpose of this study was to investigate the relationships between trunk endurance plank tests and athletic performance tests, including whether there is a relationship between long distance running and trunk endurance plank tests in adolescent male soccer players.

Study design: Cross sectional study design.

Methods: Fifty-five adolescent male soccer players performed prone and side plank tests and seven performance tests: the Cooper test, the Yo-Yo intermittent recovery test, the step 50 agility test, a 30-m sprint test, a vertical countermovement jump, a standing five-step jump, and a rebound jump. The relationships between each individual plank test, the combined score of both plank tests, and performance tests were analyzed using the Pearson correlation coefficient.

Results: The combined score of plank tests was highly correlated with the Yo-Yo intermittent recovery test ($r=0.710$, $p<0.001$), and was moderately correlated with the Cooper test ($r=0.567$, $p<0.001$). Poor correlation was observed between the prone plank test and step 50 agility test ($r=-0.436$, $p=0.001$) and no significant correlations were observed between plank tests and jump performance tests.

Conclusions: The results suggest that trunk endurance plank tests are positively correlated with the Yo-Yo intermittent recovery test, the Cooper test, and the step 50 agility test.

Level of Evidence: Level 2

Keywords: Agility, core strength, jump, long distance running, prone plank
INTRODUCTION
The trunk plays an important role in the transfer of energy and the connection of movements between the lower and upper extremities. There are many muscles within the trunk and optimal activity of these muscles is required to adjust the movement and posture of the trunk during sports activities. Thus, many athletes, including professional, amateur, and adolescent sports players perform various types of trunk exercises. In previous studies, researchers have reported that trunk exercises improve athletic performance in athletes.

It is important to assess trunk function as a part of an athlete's fitness level. Trunk function is often defined as trunk or core stability, which includes the coordination, strength, and endurance of trunk muscles. However, appropriate methods for assessing trunk function are not agreed upon. Trunk muscular endurance tests, which measure the holding time of a specific posture, are often utilized as assessment tools of trunk function. McGill's core endurance tests, comprised of the trunk flexor test, extensor test, and lateral plank test, are often used to assess trunk muscle endurance. However, there have been few published studies that have assessed the relationships between trunk endurance tests and athletic performance tests. Although Nesser et al demonstrated weak or moderate correlations between McGill's tests and athletic performance tests including sprint, jump, and agility tests in male collegiate football players, no significant correlations were found in female collegiate soccer players in another previous study. Sharrock et al also reported that no correlation existed between the leg lowering test, which is one of the standard trunk endurance tests, and performance tests in male and female collegiate athletes. Consequently, the relationship between trunk endurance tests and athletic performance tests remains unclear.

In recent research, the prone plank test has been used to assess trunk flexor endurance. Although biomechanical differences between the prone plank test and McGill's trunk flexor test have been reported, the relationships between the prone plank endurance test and athletic performance tests were not investigated. Most researchers previously investigated athletic performance test relationships using McGill's tests for college athletes, and have adopted jump, sprint, and agility tests as performance tests. However, the relationship between endurance plank tests and performance tests is not known and there has been no study that investigates the relationship in adolescent athletes specifically.

Therefore, the purpose of this study was to investigate the relationships between trunk endurance plank tests and athletic performance tests in adolescent soccer players. Because trunk endurance tests can assess muscular endurance, a hypothesis was that trunk endurance plank tests would be associated with running endurance performance.

METHODS
Participants
Fifty-five male high school soccer players (age 16.3 ± 0.5 years; height 172.6 ± 5.9 cm; weight 61.9 ± 5.7 kg) participated in this study. They were members of the same high school soccer club and were participating in soccer practices and games six times per week at the time of the investigation. Before the study, participants were interviewed about current injuries, pain, and history of injuries; they were excluded if they had any lower back pain or lower or upper extremity injuries that required treatment or which might have inhibited performance within the prior three months. The experimental protocol was explained to all participants and their parents both verbally and in written form, and their informed consent was obtained. The present study was reviewed and approved by the Institutional Ethical Committee at the University of Tsukuba, and carried out in accordance with the Declaration of Helsinki.

Procedures
Two trunk endurance tests and seven measures of athletic performance measurements were performed. For assessing the function of the trunk, two trunk endurance tests, the prone plank and side plank tests, were performed. Athletic performance measurements included the Cooper test, the Yo-Yo intermittent recovery test (YYIRT), a 30-m sprint test, the step 50 agility test, a vertical countermovement jump (CMJ), the standing five-step jump (SFSJ), and a rebound jump (RJ) for assessing endurance, intermittent endurance, sprint, agility, and jumping abili-
ties. These measurements were conducted on two separate days. On the first day, the 30-m sprint test, CMJ, RJ, and YYIRT were performed. On the second day, the trunk endurance plank tests, the SFSJ, the step 50 agility test, and the Cooper test were conducted. The YYIRT and Cooper tests were performed at the end of all measurements in order to avoid fatigue, while the other tests were performed in random order. The measurements of each day were performed after a 10-minute warm-up, which consisted of jogging, dynamic stretching, sprinting, and jumping.

Measurements
For the prone plank test, participants maintained a prone position in which the body weight was supported by the toes and forearms (Figure 1A). The side plank test was performed with the participant lying on their side, supported by the foot and elbow (Figure 1B). The side plank test was performed on both sides. Participants were instructed to maintain a neutral position of the spine and pelvis, and to breathe normally during testing. Each test was terminated when the participant was unable to maintain their posture or their pelvis moved up or down five or more cm. Each holding time was recorded using a stopwatch. The holding time of the prone plank test, right and left side plank tests, and the combined score of all plank tests were used for analyses.

The Cooper test was adopted as a continuous long distance running test. Participants ran on an outdoor track for 12 minutes. Participants were instructed to run as many laps as possible during these 12 minutes. The examiner counted the laps completed during the 12-minute test period, while calling out the elapsed time at 3, 6, 9, and 12 minutes. A measuring wheel was used to determine the fraction of the last lap completed by each participant. The total distance was reported in meters using the distance run during the number of full laps completed and the measurement of the last partial lap.

The YYIRT was performed to assess the ability to repeatedly perform high-intensity exercise. The present study adopted the YYIRT Level 2 test which consisted of two repeated 20-m runs at a progressively increasing speeds controlled by audio beeps from a tape recorder. Between each run bout the participants had a 10s rest period. When the participant failed to reach the finish line in time twice, the distance covered was recorded and represented the test result.

The 30-m sprint test was used as a measurement of speed. The sprint time for 30-m was measured using a photocell timing system (Speedtrap; Fitness Apollo Japan, Co., Ltd., Tokyo, Japan) positioned at the starting and finishing lines at a height of 1m. Participants started from a standing position, placing their forward foot 0.5m behind the sensor. Runners attempted the 30-m sprint twice. The faster time was selected for analysis.

The step 50 agility test is comprised of 50-m of running, including a change of direction and various steps, such as the crossover step and back-pedaling (Figure 2). The marker location to perform testing was arranged as published in a previous study. The

Figure 1. Trunk endurance plank tests: (A) prone plank test and (B) side plank test.
time of the step 50 agility test was measured from the signal of the start to the passing of the goal gate using the photocell timing system positioned on both sides of the goal line at a height of 1 m. Each participant performed the test twice, with a minimum three-minute rest between trials in order to avoid fatigue. The faster time was selected for analysis.

For the SFSJ, participants began the first jump from a two-legged from a standing position with feet shoulder-width apart. Then, they did 4 jumps onto a single leg, alternately, following the one-legged landing after first jump. The final landing following the fifth jump was performed with two legs. The distance from the start line to the heel of the final landing was recorded using a measuring tape. The participants performed the test twice, and the greater distance was selected for analysis.

The CMJ with arm swing was performed on a contact mat (DKH Inc., Tokyo, Japan) and jump height was calculated from the flight time using the following equation:

\[ \text{Jump height} = \left( g \times \text{flight time}^2 \right)^{8/3} \]

In this equation, \( g \) denotes the acceleration of gravity (9.81 m/s\(^2\)). The CMJ testing was performed twice, and the higher jump height was selected for analysis.

The RJ was used to assess ability of explosive power produced over repetitive jumps. This test is related to quick movements with a short ground contact time. Participants performed the RJ, which required them to repeat the vertical jump six times, using a countermovement arm swing while on the mat switch (Multi Jump Tester; DKH Inc., Tokyo, Japan). Participants were instructed to shorten contact time to the greatest extent possible and to jump as high as possible. The RJ index was calculated on the basis of jump height and contact time (jumping height / contact time).\(^5,21\) The measurement of the RJ was performed twice. The higher RJ index was selected for analysis.

Statistical analysis

All statistical analyses were performed using the SPSS 19 software (SPSS for Mac version 19; SPSS Inc. Chicago, USA). The Pearson correlation coefficient was used to determine the relationships between trunk endurance plank tests and athletic performance tests. Statistical significant was set at \( p < 0.05 \). The magnitude of correlation (\( r \)) was rated as follows: little (\( 0.00 < |r| < 0.25 \)), low (\( 0.26 < |r| < 0.49 \)), moderate (\( 0.50 < |r| < 0.69 \)), high (\( 0.70 < |r| < 0.89 \)), and very high (\(|r| > 0.90\)).\(^22\)

RESULTS

Performance variables are listed in Table 1. The correlations between the trunk endurance plank tests and athletic performance tests are presented in Table 2. High correlations were observed between the combined score of plank tests and the YYIRT (\( r = 0.710, p < 0.001 \)) (Figure 3). Further, the combined score of plank tests provided a moderate correlation with the Cooper test (\( r = 0.567, p < 0.001 \)) (Figure 4) and low correlation with the step 50 agility test (\( r = -0.365, p = 0.006 \)). Moderate and low correlations were observed between the prone plank test and YYIRT (\( r = 0.602, p < 0.001 \), Cooper test (\( r = 0.434, p = 0.001 \)), and step 50 agility test (\( r = -0.436, p = 0.001 \)). The right side plank test correlated moderately to the YYIRT (\( r = 0.590, p < 0.001 \)) and Cooper test (\( r = 0.514, p < 0.001 \)).
DISCUSSION
The present study investigated the relationships between trunk endurance plank tests and athletic performance tests. The main finding was that the combined score of plank tests showed a high correlation with the YYIRT, which requires repeated sprint performance including change of direction. Although there have been several studies regard-

| Table 1. The variables of trunk endurance plank tests and athletic performance tests |
|------------------------------------|-----------------|
| Trunk endurance plank tests        |                 |
| Prone plank test (s)               | 124.0 ± 48.8    |
| Right side plank test (s)          | 87.0 ± 25.8     |
| Left side plank test (s)           | 92.6 ± 23.0     |
| Combined score (s)                 | 303.6 ± 79.5    |
| Athletic performance tests         |                 |
| YYIRT (m)                          | 591.3 ± 228.8   |
| Cooper test (m)                    | 3245.8 ± 132.9  |
| SFSJ (m)                           | 11.03 ± 0.74    |
| Step 50 (s)                        | 15.91 ± 0.49    |
| RJ-index                           | 1.772 ± 0.416   |
| Sprint (s)                         | 4.69 ± 0.22     |
| CMJ (cm)                           | 37.82 ± 4.77    |

CMJ, vertical countermovement jump; RJ, rebound jump; SFSJ, standing five-step jump; YYIRT, Yo-Yo intermittent recovery test.

| Table 2. Correlations between trunk endurance plank tests and athletic performance tests |
|---------------------------------|-----------------|----------------|-----------------|
|                                | YYIRT           | Cooper         | SFSJ           | Step 50         | RJ index        | Sprint          | CMJ             |
| Prone plank test               |                 |                |                |                |                |                |                 |
| .602**                         | .434**          | .124           | -.436**        | .169            | -.273*          | .172            |
| Right side plank test          |                 |                |                |                |                |                |                 |
| .590**                         | .514**          | .152           | -.222           | .244            | -.242           | .125            |
| Left side plank test           |                 |                |                |                |                |                |                 |
| .515**                         | .464**          | -.023          | -.088           | .166            | -.135           | -.043           |
| Combined score                 |                 |                |                |                |                |                |                 |
| .710**                         | .567**          | .119           | -.365**         | .231            | -.285*          | .133            |

* Significant correlation (p<0.05)
** Significant correlation (p<0.01)

CMJ, Vertical countermovement jump; RJ, Rebound jump; SFSJ, Standing five-step jump; YYIRT, Yo-Yo intermittent recovery test.
ing the relationships between the trunk endurance tests and athletic performance tests, this is the first study to demonstrate high and moderate correlations between tests.

In the current study, significant correlations with the trunk endurance plank tests were in running performance tests, but not in jump performance tests. Notably, the YYIRT demonstrated a higher correlation than other running performance tests. The YYIRT requires sprinting and change of direction and can assess intermittent anaerobic endurance ability. In the current study, low and moderate correlations were found between the plank tests and sprint, agility, and the Cooper tests. Because the YYIRT measures several aspects of athletic abilities, this could explain it being highly correlated with the plank tests. Previous studies that have used other trunk flexor tests have not investigated the relationship between the trunk endurance test and running endurance tests. The trunk endurance plank tests used in this study, as well as other trunk endurance tests, assess the trunk muscle endurance by requiring the subject to isometrically maintain the same posture for the duration of the test. Sasaki et al have reported that change of direction performance correlated with the trunk angular displacement during the change of direction. Moreover, excessive motions of the trunk, particularly trunk rotation, interfere with the efficient transfer of energy during running-based sports activities. Thus, the control of trunk movement is important for movement efficiency during running as well as change-of-direction performance. In previous studies, it has been reported that trunk exercise programs, which were designed to enhance core stability or strength, improved the results of the Cooper test and the 5,000m time trial. The current study demonstrated a moderate correlation between combined trunk plank test scores and the Cooper test. These results indicate that trunk plank tests may be related to running performance, and therefore may be useful tools for assessing abilities of athletes whose require intermittent and continual endurance performance and change of direction, such as soccer and basketball players. It should be noted, however, that a limitation of this study is that the tests were only conducted on adolescent male soccer players. These results may not be seen in female soccer players or athletes of other age groups.

In contrast, there were no significant correlations between trunk endurance plank tests and jump performance tests. Trunk function appears important for jump performance as many researchers have reported that a trunk exercise program enhanced the CMJ and RJ. Although researchers have demonstrated a moderate correlation between McGill’s tests and CMJ performance, several other researchers have demonstrated no significant correlation between trunk endurance tests and CMJ performance. The results of this study could not confirm the relationship between trunk muscular endurance and jump performance. Trunk abilities required for the trunk endurance tests and jump performance are different. Thus, trunk endurance tests, including the plank tests, may not appropriately assess trunk flexor muscle strength.
function required for jumping performance. Each jumping act is performed explosively and rapidly. Consequently, coordination of trunk muscles and instantaneous control of the position and movements of the trunk during dynamic motion are required. Future research considering the other trunk function tests, including instantaneous trunk control, is needed to better understand this relationship.

**CONCLUSION**

The results of the current study demonstrated a high correlation between the combined score of trunk endurance plank tests and the YYIRT and a moderate correlation with the Cooper test. Moreover, the prone plank test showed moderate and low correlations with the YYIRT, Cooper test, the step 50 agility test, and the 30m sprint test. These results suggest that trunk plank tests may be able to utilize to assess trunk function of athletes whose activities require intermittent and continual endurance performance and change of direction, such as soccer players.

**REFERENCES**


ABSTRACT

**Background:** Hip abductor tendon (HAT) tearing is commonly implicated in greater trochanteric pain syndrome (GTPS), though limited information exists on the disability associated with this condition and specific presentation of these patients.

**Purpose:** To describe the clinical, functional and biomechanical presentation of patients with symptomatic HAT tears. Secondary purposes were to investigate the association between these clinical and functional measures, and to compare the pain and disability reported by HAT tear patients to those with end-stage hip osteoarthritis (OA).

**Study Design:** Prospective case series.

**Methods:** One hundred forty-nine consecutive patients with symptomatic HAT tears were evaluated using the Harris (HHS) and Oxford (OHS) Hip Scores, SF-12, an additional series of 10 questions more pertinent to those with lateral hip pain, active hip range of motion (ROM), maximal isometric hip abduction strength, six-minute walk capacity and 30-second single limb stance (SLS) test. The presence of a Trendelenburg sign and pelvis-on-femur (POF) angle were determined via 2D video analysis. An age matched comparative sample of patients with end-stage hip OA was recruited for comparison of all patient-reported outcome scores. Independent t-tests investigated group and limb differences, while analysis of variance evaluated pain changes during the functional tests. Pearson's correlation coefficients investigated the correlation between clinical measures in the HAT tear group.

**Results:** No differences existed in patient demographics and patient-reported outcome scores between HAT tear and hip OA cohorts, apart from significantly worse SF-12 mental subscale scores (p=0.032) in the HAT tear group. Patients with HAT tears demonstrated significantly lower (p<0.05) hip abduction strength and active ROM in all planes of motion on their affected limb. Pain significantly increased throughout the 30-second SLS test for the HAT tear group, with 57% of HAT tear patients demonstrating a positive Trendelenburg sign. POF angle during the test was not significantly associated with pain.

**Conclusion:** Patients with symptomatic HAT tears demonstrate poor function, and report pain and disability similar to or worse than those with end-stage hip OA. This information better defines and differentiates the presentation of these patients.

**Level of Evidence:** Level 3 case-controlled study, with matched comparison

**Keywords:** Assessment, clinical outcomes, hip abductor tears, patient presentation
INTRODUCTION

Greater trochanteric pain syndrome (GTPS) is a non-specific term used to describe the clinical condition of greater and peri-trochanteric hip pain and tenderness. It affects 10-25% of the general population, and is more prevalent in females and sedentary 40–60 year olds. While a number of conditions are associated with GTPS including trochanteric bursitis, external coxa saltans and gluteal tendinopathy, better understanding of the condition along with advanced imaging and surgical findings has revealed a common cause to be hip abductor tendon (HAT) tears. While the true incidence of hip abductor tendon tears is unknown, it has been estimated that almost 25% of late-middle aged women and more than 10% of late-middle aged men will develop a HAT tear.

GTPS is generally characterized by pain in the lateral hip and/or buttck, often radiating laterally and/or posteriorly down the thigh, and occasionally below the knee. There is tenderness on palpation over the greater trochanter, with pain aggravated further by pressure, as well as lying on the affected side. While it has been reported that hip ROM is often not affected in GTPS patients, patients with hip abductor tears generally limp during ambulation making improvement of limp a common goal of surgical repair. GTPS patients also experience pain/difficulty with prolonged standing or transitioning to a standing position, climbing stairs and sitting with the affected leg crossed. Resisted hip external rotation (in flexion) has demonstrated high sensitivity (88%) and specificity (97.3%) for abductor tendon tears. Pain with sustained single leg stance beyond 30 seconds may also be a useful clinical test.

While the aforementioned findings have been generalized to patients with GTPS, there is no research that has attempted to identify the specific presentation of patients with symptomatic HAT tears. Earlier identification of HAT tears may permit early intervention and more targeted management and/or referral strategies for the therapist, assist in developing specific clinical evaluation tools for patients with a diagnosis of GTPS and/or HAT tears or those presenting with lateral hip pain, and permit better design of future studies investigating the conservative and surgical treatment of tendon tears. Patients with symptomatic HAT tears often go undiagnosed in GTPS sufferers for some time, or are misdiagnosed as 'bursitis' or 'hip OA', which may explain the long duration of symptoms and failed conservative treatments these patients often endure. Therefore, the purpose of this study was to describe the clinical, functional and biomechanical presentation and disability of patients with symptomatic HAT tears. Secondary purposes were to investigate the association between these clinical and functional measures, and to compare the pain and disability reported by patients with HAT tears to those with end-stage hip OA.

METHODS

Hip Abductor Tendon (HAT) Tear Patients

Between August 2012 and March 2016, a consecutive series of 149 patients with symptomatic HAT tears (128 females, 21 males) were referred for pre-operative counselling and clinical evaluation prior to their scheduled HAT repair. The clinical diagnosis of HAT tearing was confirmed by Magnetic Resonance Imaging (MRI) in all patients and included partial and full thickness tears of gluteus medius and/or minimus. For the current analysis, patients were excluded if they were symptomatic bilaterally (n=8) or had evidence of advanced (Grade 2-4) and/or symptomatic hip OA on MRI (n=8). In all included patients, the predominant presenting symptom was lateral-sided trochanteric pain with radiation down the lateral leg, and not below the knee joint line. Patients were also excluded if they had undergone prior hip surgery including THA (n=12), prior failed HAT repair (n=2), ITB release and/or bursectomy (n=2). The analysis was completed with 124 patients (104 females, 20 males), with a mean age of 63.4 years (range 43-82) and body mass index (BMI) of 27.6 (range 20.0-40.2) (Table 1). Patients had undergone an average of 3.1 (range 1-8) prior corticosteroid injections and reported a mean duration of symptoms (DOS) of 3.6 years (range 6 months – 18 years). Patients provided written informed consent prior to study enrolment, and ethics approval was obtained from the Hollywood Private Hospital Human Research Ethics Committee (HPH348). This study conformed to the STROBE (Strengthening the reporting of observational studies in epidemiology) checklist.
Hip Osteoarthritis Patients
A total of 30 patients with end-stage hip OA scheduled for THA were recruited to provide comparison of specific patient-reported outcome (PRO) measures used in the current study, to that of patients with symptomatic HAT tears (Table 1). Given GTPS is a condition more prevalent in females and the cohort with HAT tears confirmed this, in order to best match the groups targeted sampling was utilized to attain a comparable female/male ratio. Therefore, once the group with HAT tears was confirmed (n=124, 104 females, 20 males, [16% males]), recruitment of males with end-stage hip OA was ceased at n=5 (17% of 30 patients) and female recruitment continued until the total of 30 patients was reached. This hip OA group then included 25 females and five males, with a mean age of 63.2 years (range 44-77) and BMI of 27.1 (range 18.4-33.6) (Table 1). While none of the hip OA patients presented with lateral hip pain and/or tenderness (with or without pain radiating laterally and/or posteriorly down the outer thigh), no attempt was made to diagnose the presence or absence of asymptomatic underlying GTPS pathology via ultrasound or MRI in the hip OA group.

Patient-reported Outcome (PRO) Measures
All HAT tear and hip OA patients completed a number of PRO measures to evaluate hip pain, symptoms and disability, including the Harris Hip Score (HHS)20 and Oxford Hip Score (OHS)21,22. While these clinical tools have not been validated in a cohort with GTPS or HAT tears, nor have any existing hip PROs, we employed them given they had been the two most commonly utilized clinical tools for assessing outcomes before and after HAT repair surgery.23 The 12-item Short Form Health Survey (SF-12) was also employed, which evaluated the general health of the patient producing a mental (MCS) and physical component subscale (PCS).

An additional series of questions was compiled and completed by all HAT tear and hip OA patients, which were grouped to form a novel PRO (Table 2). For the purpose of this manuscript it has been called the ‘GTPS PRO’, and it was used to quantify the severity of common symptoms, impairments and functional limitations reported by patients with GTPS that are often excluded from existing hip PRO scores. The final list of 10 items was decided upon by the author team, following review of existing hip PROs and patient cohorts they were originally developed for (i.e. hip OA patients), along with 10 years of clinical and anecdotal experience the author team has with operating on and rehabilitating patients with HAT tears. The GTPS PRO items were each scored on a scale from 0 (None) to 5 (Extreme) (Table 2).

Functional and Biomechanical Measurement Procedures
The patients with HAT tears performed a series of functional tests, each administered by a single physical therapist with 15 years of clinical experience, particularly with undertaking the chosen tests. First, active hip range of motion (ROM) was evaluated on

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Table 1. Characteristics of the hip abductor tendon tear (HAT) and end-stage hip osteoarthritis (OA) patient groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>HAT Patients (n=124)</th>
<th>End-stage Hip OA Patients (n=30)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (female/male)</td>
<td>104/20</td>
<td>25/5</td>
<td>N/A</td>
</tr>
<tr>
<td>Age (y)</td>
<td>63.4 (9.3)</td>
<td>63.2 (9.4)</td>
<td>0.801</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.64 (0.07)</td>
<td>1.70 (0.09)</td>
<td>0.499</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>74.4 (14.9)</td>
<td>76.2 (16.2)</td>
<td>0.184</td>
</tr>
<tr>
<td>Body Mass Index</td>
<td>27.6 (4.7)</td>
<td>27.1 (4.1)</td>
<td>0.280</td>
</tr>
<tr>
<td>Injections (n)</td>
<td>3.1 (1.8)</td>
<td>2.0 (0-4.0)</td>
<td>N/R</td>
</tr>
<tr>
<td>Duration of Symptoms (y)</td>
<td>3.6 (2.2)</td>
<td>0.5-18</td>
<td>N/R</td>
</tr>
</tbody>
</table>

NR = not reported; N/A = not applicable.
both the affected and unaffected limb in all planes using either a hand-held bubble inclinometer (hip flexion in supine, internal and external rotation in prone) or a Jamar® long arm goniometer (hip adduction and abduction in supine, extension in standing). These positions of active hip ROM evaluation were chosen with factors in mind such as assessor ease and accuracy, minimizing the gravitational component of lifting a limb, patient comfort and not being as restricted in measurement by concomitant musculoskeletal pathology or abnormality (such as restricted hip and/or knee flexion could limit accuracy of measurement of hip internal and/or external rotation in a flexed hip position). Standardized feedback was provided across all patients in undertaking the aforementioned measures, and patients were instructed to work into each plane of motion as far as they possibly could to the end point of range, or to when pain could no longer be tolerated. All patients were educated on potential compensatory movements (i.e. such as forward trunk lean and excessive lumbar lordosis during standing hip extension), and these compensatory mechanisms were monitored and addressed as required by the assessor. For all planes of active hip ROM, absolute values and limb symmetry indices (LSIs) were calculated (LSIs were expressed as the range of the affected limb, as a percentage of the unaffected limb).

Second, a 30-second single leg stance (SLS) test was conducted, almost identically to that previously used in patients with gluteal tendinopathy. While the originally published test requires patients to report the presence/absence of hip pain within 0–5 seconds (immediate), 6–15 seconds (early) and/or or 16–30 seconds (late), patients were asked to verbally report their severity of pain immediately prior to the initiation of the test and then at 10, 20 and 30 seconds into the test, on a whole number rating scale (NRS) of 0 (no pain) to 10 (worst pain). In addition, frontal plane hip biomechanical parameters were evaluated from video obtained using a Sony HDR-PJ200 digital video camera (Sony Corporation, Tokyo, Japan) which was set up approximately three meters in front of the patient, with the camera height set at the level of the anterior superior iliac spines (ASISs). The on-screen video camera display was then zoomed as required to ensure the feet could be viewed and the patient's head was truncated (Figure 1). Video was collected during the entire duration of the 30-second SLS test. Patients wore comfortable pants and walking shoes throughout all tests and, prior to testing, three

| Table 2. The Greater Trochanteric Pain Syndrome Patient-reported Outcome (GTPS PRO) score, which included additional items aimed at investigating common symptoms, impairments and functional limitations reported by patients with GTPS |
|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| 1. Do you have any pain: | None | Very mild | Mild | Moderate | Severe | Extreme |
| a) Over the outside of your hip? | 0 | 1 | 2 | 3 | 4 | 5 |
| b) Over the outside of your thigh? | 0 | 1 | 2 | 3 | 4 | 5 |
| c) With pressure (or pressing) on your outer hip area? | 0 | 1 | 2 | 3 | 4 | 5 |
| d) Radiating down to your knee? | 0 | 1 | 2 | 3 | 4 | 5 |
| c) When your affected leg is crossed over your other leg? | 0 | 1 | 2 | 3 | 4 | 5 |
| 2. Do you have any pain and/or difficulty: | | | | | | |
| a) Sleeping on your affected side? | 0 | 1 | 2 | 3 | 4 | 5 |
| b) Standing on your affected leg? | 0 | 1 | 2 | 3 | 4 | 5 |
| 3. Because of your hip, do you: | | | | | | |
| a) Limp during walking? | 0 | 1 | 2 | 3 | 4 | 5 |
| b) Fatigue quickly during undertaking normal daily activities? | 0 | 1 | 2 | 3 | 4 | 5 |
| c) Use a walking aid (i.e. crutch) or shopping trolley at the shops? | 0 | 1 | 2 | 3 | 4 | 5 |
Retro-reflective markers were attached to the skin of the pelvis (left and right ASIS) and sternal notch. For patients in which the centre of the patella could not be easily observed visually, a fourth marker was placed in the central patella (Figure 1). Once captured, video images of the 30-second SLS test (on the affected limb) were projected onto a 19-inch flat screen monitor and digitised using Silicon Coach Professional (Silicon Coach Professional Version 6.0, Dunedin, New Zealand). The video data in this study was used to evaluate pelvis-on-femur (POF) angle during the 30-second SLS test at the aforementioned time points (immediately prior to the start of the test during bilateral weight bearing stance, and at 10, 20 and 30 seconds into the test). POF angle (degrees) was measured as an angle made between the ASIS on the unaffected swing leg, the ASIS on the affected support leg and the knee joint centre on the affected support leg (Figure 1).

Third, patients with HAT tears performed the six minute walk test (6MWT) to assess the maximum comfortable distance the patient could walk in a six minute time period. The patient was instructed to walk back and forth between two markers set 25 m apart, and asked to walk “as far and fast as they comfortably could for the entire six minutes”. A NRS (0 = no pain; 10 = worst pain) was again employed immediately prior to the test and then at 2, 4 and 6 minutes into the test, to evaluate pain severity.

Finally, the maximal isometric hip abduction strength was assessed on both the affected and unaffected limb in HAT tear patients, using a T5 Cable Tensiometer (Pacific Scientific Company, Los Angeles). In an upright standing position, with the patient able to bear as much weight as was required through their upper body supported alongside their trunk, patients were asked to abduct their leg as hard as they could against the cable anchored just above their lateral malleolus (Figure 2). The test was undertaken three times for each limb, initiated on the unaffected limb and then alternated between the unaffected and affected side, with the maximum score of the three trials used for analysis. The patient was instructed to maintain an upright trunk and not force their hips out with the test leg and, therefore, to ensure this was the case the hands of the assessor were placed on either hip of the patient during the test to minimize compensatory strategies that can occur in standing. Other studies have evaluated hip abductor strength in the side lying position, and evaluating abductor strength in side lying is frequently employed in clinical settings. However, the evaluation of limb symmetry limited the applicability of using the side lying position due
to compression pain when lying on the affected limb, while evaluating the non-affected limb. Supine (neutralizes the gravitational effect and avoids the requirement of individuals lying on their injured side) and standing (reported to be more functional as the majority of daily living activities involve hip abduction performed in this position) positions has also been employed, so the supported standing position was employed. For strength, absolute values and limb symmetry indices (LSIs) were calculated (LSIs were expressed as the strength of the affected limb, as a percentage of the unaffected limb).

Data and Statistical Analysis
Means, standard deviations and ranges were calculated for all PRO, clinical and biomechanical outcomes. Independent t-tests were employed to evaluate differences in patient demographics between the HAT tear and end-stage hip OA cohorts, as well as all PRO measures. Within the HAT tear cohort, paired sample t-tests were used to investigate differences between the affected and unaffected limb in active hip ROM and hip abduction strength. A one-way repeated measures analysis of variance (ANOVA) was used to evaluate the change in pain during the 6MWT, as well as the change in pain and POF angle during the 30-second SLS test, as well as the association between the two variables. In the presence of significant ANOVA results, t-tests were further employed to see between which time points these differences indeed occurred. Pearson’s coefficients were used to investigate the correlations between PROs (HHS, OHS and SF-12), functional measures (six minute walk distance, maximal isometric hip abductor strength, limb symmetry index between the affected and unaffected limb in hip abductor strength and active ROM measures) and pain (upon completion of the 6MWT and 30-second SLS test). Statistical analysis was performed using SPSS software (SPSS, Version 17.0, SPSS Inc., USA), while statistical significance was determined at $p<0.05$.

RESULTS
Of the 124 HAT tear patients included in this analysis, all patients completed the aforementioned PRO measures, active hip ROM evaluation and 6MWT. One HAT tear patient was unable to complete the maximal isometric hip abduction strength assessment, while five HAT tear patients were unable to undertake the 30-second SLS test or 6MWT, all due to the requirement of a single forearm crutch.

No differences existed in patient demographics between the HAT tear and hip OA cohorts (Table 1). While the HAT tear group reported a significantly worse score for the SF-12 MCS ($p=0.032$), no other differences ($p>0.05$) in the validated PRO measures
existed between the HAT tear and hip OA groups (Table 3). For the GTPS PRO, HAT tear patients reported a significantly higher level (p<0.05) of pain and/or difficulty when compared to the hip OA patients, in nine of the 10 included items (the only question that was not significantly different between the HAT tear and hip OA patients was the patient’s subjective report of a limp during walking) (Table 3).

For the HAT tear cohort, active hip ROM in all planes was significantly lower (p<0.05) on the affected limb, compared with the unaffected limb, with the mean LSI for active hip flexion at 86.2% though all other hip ROM LSIs below 80% (Table 4). While the LSI for maximal isometric hip abduction strength was 92.7%, it was still significantly lower (p<0.05) on the affected limb, compared with the unaffected limb (Table 4). During the 30-second SLS test, reported pain in the HAT tear group significantly increased from 2.3 immediately prior to the test to 5.1 upon its completion, and t-tests indicated that pain significantly increased between every time point up until the completion of the test. At the completion of the test, 93% (n=111) of HAT tear patients reported pain, with 57% (n=68) of patients demonstrating a positive Trendelenburg sign (Table 5). POF angle during the test did not significantly change, and no significant correlation existed between pain and POF angle throughout the test (Table 5). A mean of 391m was observed for the 6MWT in HAT tear patients, with

### Table 3. Patient reported outcome (PRO) measures for the hip abductor tendon (HAT) tear and end-stage hip osteoarthritis (OA) patient groups. Data presented as means (SD) and ranges

<table>
<thead>
<tr>
<th>PRO Measure</th>
<th>Harris Hip Score (0-100)</th>
<th>Oxford Hip Score (0-48)</th>
<th>SF-12 (PCS)</th>
<th>SF-12 (MCS)</th>
<th>GTPS PRO score items (1-10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1A</td>
</tr>
<tr>
<td>HAT Tear Patients</td>
<td>60.7 (19.6)</td>
<td>25.9 (8.4)</td>
<td>34.6 (10.1)</td>
<td>43.9 (11.8)</td>
<td>3.1</td>
</tr>
<tr>
<td>Range</td>
<td>22.8-100</td>
<td>11-46</td>
<td>9.0-57.8</td>
<td>20.4-70.8</td>
<td>1-4</td>
</tr>
<tr>
<td>End-stage Hip OA Patients</td>
<td>60.8 (15.5)</td>
<td>27.0 (7.2)</td>
<td>36.8 (8.8)</td>
<td>54.3 (9.9)</td>
<td>1.1</td>
</tr>
<tr>
<td>Range</td>
<td>23.0-88.6</td>
<td>11-40</td>
<td>19.2-56.7</td>
<td>31.6-70.6</td>
<td>0-3</td>
</tr>
<tr>
<td>p value</td>
<td>0.983</td>
<td>0.586</td>
<td>0.331</td>
<td>0.032</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

SF-12 = 12 item short form health survey, PCS = physical component score, MCS = mental component score, GTPS PRO (Greater Trochanteric Pain Syndrome Patient-reported Outcome).

### Table 4. Maximal isometric hip abductor strength and active range of motion between the affected and unaffected sides in the hip abductor tendon (HAT) tear patient group. Data are presented using means (SD) and range for the affected and unaffected limbs, along with p values. Limb Symmetry Indices (LSIs) are also shown for each variable (the affected limb as a percentage of the unaffected limb)

<table>
<thead>
<tr>
<th>Hip</th>
<th>Maximal Isometric Hip Abductor Strength (kg)</th>
<th>Flexion (degrees)</th>
<th>Extension (degrees)</th>
<th>Abduction (degrees)</th>
<th>Adduction (degrees)</th>
<th>External Rotation (degrees)</th>
<th>Internal Rotation (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aaffected Hip</td>
<td>15.9 (3.5)</td>
<td>102.8 (17.4)</td>
<td>14.2 (5.2)</td>
<td>31.6 (12.1)</td>
<td>15.9 (6.3)</td>
<td>30.3 (8.9)</td>
<td>26.7 (10.8)</td>
</tr>
<tr>
<td>Range</td>
<td>10.8-26.8</td>
<td>60-140</td>
<td>5-27</td>
<td>5-58</td>
<td>7-42</td>
<td>8-50</td>
<td>5-50</td>
</tr>
<tr>
<td>Unaffected Hip</td>
<td>17.4 (4.7)</td>
<td>119.3 (9.7)</td>
<td>20.8 (5.7)</td>
<td>45.7 (9.2)</td>
<td>24.2 (7.6)</td>
<td>38.1 (7.6)</td>
<td>38.8 (7.8)</td>
</tr>
<tr>
<td>p value (affected versus unaffected side)</td>
<td>0.002</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Limb Symmetry Index (LSI)</td>
<td>92.7%</td>
<td>86.2%</td>
<td>68.3%</td>
<td>69.1%</td>
<td>65.7%</td>
<td>79.5%</td>
<td>68.8%</td>
</tr>
</tbody>
</table>
pain significantly increasing over the duration of the test (Table 6). T-tests indicated that pain significantly increased between every time point up until the completion of the 6MWT.

The HHS, OHS and SF-12 PCS reported in the HAT tear group were all significantly correlated with each other (Table 7), with the strength of these associations generally good to excellent. The SF-12 MCS was not significantly associated with any other PROs (Table 7), with the strength of associations between the SF-12 MCS and other PROs fair at best. The HHS, OHS and SF-12 PCS were all significantly and negatively correlated with active hip flexion, abduction, adduction and external rotation ROM (Table 7). While this indicated that a greater limb symmetry deficit between the affected and unaffected limbs in these active ROM measures was associated with poorer clinical status in HAT tear patients, the strength of these associations was fair at best. The HHS, OHS and SF-12 PCS were positively correlated with six-minute walk distance with the strength of associations moderate-good. These PROs were also significantly and negatively correlated with pain upon completion of both the 6MWT and 30-second SLS test (Table 7), with the strength of associations good-excellent. Maximal isometric hip abductor strength on the affected limb, six–minute walk distance, pain upon completion of the 6MWT and pain at completion of the 30-second SLS test, were all significantly correlated with each other (Table 7), though the strength of these associations were varied and ranged from fair-excellent. The limb symmetry deficit in maximal isometric hip abductor strength between the affected and unaffected limbs in HAT tear patients was not significantly correlated with any of the other scores.

**DISCUSSION**

GTPS encompasses a range of conditions; however, advanced imaging and surgical findings have revealed that HAT tears may be a strong contributing factor to the pain and disability in GTPS patients.

<table>
<thead>
<tr>
<th>Time</th>
<th>Pain, n (%)</th>
<th>Pain (0-10)</th>
<th>+ve Trendelenburg Sign (n)</th>
<th>POF Angle (degrees)</th>
<th>Correlation (p value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>78 (66%)</td>
<td>2.3 (0-8)</td>
<td>N/A</td>
<td>85.0 (78-89)</td>
<td>N/A</td>
</tr>
<tr>
<td>10 secs</td>
<td>104 (87%)</td>
<td>3.9 (0-9)</td>
<td>62</td>
<td>85.1 (75-94)</td>
<td>-0.15 (0.212)</td>
</tr>
<tr>
<td>20 secs</td>
<td>108 (91%)</td>
<td>4.6 (0-10)</td>
<td>62</td>
<td>84.7 (73-92)</td>
<td>-0.10 (0.530)</td>
</tr>
<tr>
<td>30 secs</td>
<td>111 (93%)</td>
<td>5.1 (0-10)</td>
<td>68</td>
<td>83.1 (73-92)</td>
<td>-0.15 (0.302)</td>
</tr>
<tr>
<td>p value</td>
<td>N/A</td>
<td>&lt;0.0001</td>
<td>N/A</td>
<td>0.200</td>
<td>N/A</td>
</tr>
</tbody>
</table>

N/A – not applicable

<table>
<thead>
<tr>
<th>6MWT Distance (m)</th>
<th>Pain (pre-test)</th>
<th>Pain (2 mins)</th>
<th>Pain (4 mins)</th>
<th>Pain (6 mins)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>391 (108)</td>
<td>2.9 (2.5)</td>
<td>3.9 (2.8)</td>
<td>4.5 (2.9)</td>
<td>5.2 (2.9)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>105-581</td>
<td>0-8</td>
<td>0-9</td>
<td>0-10</td>
<td>0-10</td>
<td></td>
</tr>
</tbody>
</table>
While the general presentation of patients with GTPS has been reported, there is no research that has attempted to identify the specific presentation and level of disability in symptomatic HAT tear patients. An improved understanding of these patients may allow better differentiation from other presenting conditions, such as hip OA, which may permit more targeted management and/or referral strategies for the therapist. Therefore, this study aimed to define the clinical presentation and disability associated with these tendon tears, as well as to investigate the association between different clinical measures and compare the pain and disability reported in those with HAT tears to patients with end-stage hip OA.

The results of this study demonstrated that patients with symptomatic HAT tears report pain and disability similar to those with end-stage hip OA. Furthermore, the SF-12 MCS was significantly lower in HAT tear patients, compared to OA patients, suggesting a significantly higher perceived level of disability and poorer quality of life in those with HAT tears. Fearon et al. recently suggested that people with GTPS demonstrate low levels of fulltime work participation, high levels of pain and dysfunction, and a reduced quality of life, indistinguishable from people with severe OA of the hip. The current study supports some of these previous findings.

Existing PROs may not capture the unique areas of pain, difficulty and/or dysfunction reported in GTPS and HAT tear patients. Many areas of concern commonly reported by GTPS patients are not included in the existing PROs; likely given they were originally developed for patients with hip fracture, OA or those undergoing THA.20-22,30-43 Hip arthroscopy patients are younger, with a goal to often return to sports activities.44 Therefore, other hip PRO measures were developed for those undergoing hip arthroscopy and/or hip-related pathologies specifically seen in young-to-middle-aged people.45-48 Patients with hip tendon pathology (and tears) are often not young patients, and often do not have co-existent intra-articular pathology or symptomatic hip OA. GTPS patients often report lateral hip and/or buttock pain,14,15 that may radiate laterally down the thigh and occasionally below the knee.15 There is often tenderness on trochanteric palpation, with pain aggravated by lying on the affected side.6 GTPS patients experience pain/
difficulty with prolonged standing or transitioning to a standing position, climbing stairs and sitting with the affected leg crossed.6

With this in mind, only one of aforementioned hip PRO measures inquires about pain/difficulty when sleeping on the affected side, while none inquire about lateral trochanteric pain and/or tenderness. None of the available hip PROs inquire about pain when standing on the affected limb, nor sitting with the affected leg crossed. Furthermore, few PROs inquire about the use of walking aids and only the HHS and OHS enquire about limp severity. Therefore, the GTPS PRO was developed by the authors, which aims to investigate and rate common symptoms, impairments and functional limitations reported by patients with GTPS that are often excluded from existing hip PRO scores. Apart from the presence of a limp during walking, patients with symptomatic tendon tears reported significantly more pain and/or difficulty than patients with end-stage hip OA in all remaining items.

It has been previously reported that hip movement is generally not affected in GTPS patients, largely due to the fact that these patients do not have OA.3 However, this was not the case in the current study whereby patients with HAT tears demonstrated significantly reduced active hip ROM in all planes, compared with their unaffected side. Extremes of hip movement may be limited in the HAT tear patients due to pain that may occur with increased hip abductor activation and/or compression over the greater trochanter. In particular, positions of increased HAT compression over the greater trochanter and increased likelihood of provocation may include internal hip rotation, excessive hip adduction and/or flexion.54,55

Patients attained a mean of 391 meters during the 6MWT, with a significant increase in reported pain throughout the test. Higher reported pain and less distance covered during the test were significantly associated with poorer PRO scores in HAT tear patients. While six-minute walk capacity has not been evaluated in HAT tear patients previously, and it was not evaluated in the matched hip OA cohort, more recent existing literature in hip OA patients has demonstrated a mean of 643 meters in patients with radiographic and symptomatic hip OA56 as well as 450 meters57 and 452 meters58 in patients with end-stage hip OA scheduled for THA. Again, the current results reflect the severity and disability associated with symptomatic HAT tears.

While a significantly reduced isometric hip abductor strength profile was demonstrated in the affected limb of HAT tear patients, compared with the unaffected contralateral side, mean LSI values for hip abductor strength were still 93%. Furthermore, given that the hip abductor strength LSI was not significantly correlated with any of the other PROs or functional scores, the clinical relevance of the side-to-side strength difference remain unclear. However, this hip abductor strength deficit may be important to pelvic stability during weight bearing and SLS, and this study did report that of the 119 patients that completed the 30-second SLS test, 62 demonstrated a positive Trendelenburg sign at 10 seconds into the test, with 68 upon completion. Interestingly, while POF angle did decrease throughout the duration of the test, this fall was not statistically significant.

There are several inherent study limitations. First, this research was conducted using symptomatic HAT tear patients that had sought medical opinion for their condition and were planning to undergo HAT repair surgery. Therefore, this research cannot be generalized across all patients with tears, including those that are otherwise asymptomatic. Second, while an outcome of this study was to compare reported pain and disability of HAT tear patients to a group of patients with end-stage hip OA, an attempt to differentiate further to those with isolated bursitis or other conditions that may contribute to GTPS has not been made. This remains an area for future research, and in the authors’ experience these tears often go misdiagnosed for hip OA or ‘bursitis’, or undiagnosed in GTPS sufferers for some time. This may explain the long duration of symptoms (mean 3.6 years) and failed conservative treatments (mean 3.1 injections) reported in this study.

Third, there are known limitations with the accuracy of assessing joint ROM using handheld goniometry, though it has been reported that the reliability of measurements improves when the assessment is performed by the same individual, using the same measurement tool and in standardized test positions.59,60 Furthermore, active, rather than active-
assisted or passive hip ROM was evaluated, with an underlying goal to assess how far each patient could actively move their hip into each plane of motion. However, it should be acknowledged that both active and passive ROM assessment may offer benefits in patient evaluation, particularly when looking to discriminate between those with HAT tendinopathy/tears and hip OA. Fourth, as mentioned previously hip abduction strength was evaluated in the supported standing position and, while compensatory mechanisms can be adopted in this position by patients, every effort was made to minimize these as discussed.

Fifth, 2D video imaging of patients was undertaken during their 30-second SLS test to more accurately evaluate the presence/absence of a Trendelenburg sign and measure POF angle (hip adduction) during weight bearing, along with its association with reported hip pain. While it was not the aim of this study, other biomechanical variables assessed during single limb weight bearing activities may add value to the functional evaluation of HAT tear patients, including lateral pelvic translation and compensatory trunk lean over the ipsilateral weight bearing hip. Finally, a number of validated hip PRO measures exist and this study employed the HHS and OHS primarily to evaluate hip pain, symptoms and disability. This was in part due to the lack of a validated PRO measure for GTPS or HAT tear patients at study onset. However, the HHS and OHS have been reported as the two most common clinical tools used to evaluate the outcome of patients before and after HAT repair surgery. Nevertheless, patients scored poorly in the HHS and OHS in this study, and these scores were comparable to those with end-stage hip OA. While we administered a series of additional questions to investigate concerns pertinent to GTPS patients that are often not included in other hip PROs, a PRO specific to evaluating the pain and disability associated with GTPS has been developed and validated more recently, and could be employed in future research.

**CONCLUSION**

This is the first study to describe the specific clinical presentation and reported disability of patients with symptomatic HAT tears. These patients report pain severity and disability levels similar (or worse, as was the case with the SF-12 MCS) to that of patients with end-stage hip OA though, as expected, also report significantly more pain and/or difficulty in items specific to patients with GTPS. Patients displayed reduced active hip ROM and abductor strength, with poor six-minute walk performance that was worse than that reported in existing literature evaluating hip OA patients. The majority of patients demonstrated a positive Trendelenburg sign during the 30-second SLS test with pain significantly increasing throughout the test. This information should help the clinician to differentiate patients presenting with HAT tears or hip OA. Understanding the presentation of patients with HAT tears may stimulate future research about diagnosis and treatment of this condition.

**REFERENCES**


ABSTRACT

Background and Purpose: Range of motion deficits at the hip and glenohumeral joint (GHJ) may contribute to the incidence of injury in softball players. With injury in softball players on the rise, softball related studies in the literature are important. The purpose of this study was to examine hip and GHJ passive range of motion (PROM) patterns in collegiate softball players.

Hypothesis: It was hypothesized that the position players would exhibit significantly different PROM patterns than pitchers. Additionally, position players would exhibit significantly different side-to-side differences in PROM for both the hip and GHJ compared to pitchers.

Study Design: Prospective cohort study.

Methods: Forty-nine collegiate softball players (19.63 ± 1.15 years; 170.88 ± 8.08 cm; 72.96 ± 19.41 kg) participated. Passive hip and GHJ internal (IR) and external rotation (ER) measures were assessed. Glenohumeral PROM was measured with the participants supine with the arm abducted to 90°. The measurements were recorded when the scapula began to move or a firm capsular end-feel was achieved. The hip was positioned in 90° of flexion and passively rotated until a capsular end-feel was achieved. Total PROM was calculated by taking the sum of IR and ER for both the hip and GHJ.

Results: No significant side-to-side PROM differences were observed in pitchers, at the GHJ or hip joint. Position players throwing side hip IR was significantly greater than the non-throwing side hip (p = 0.002). The non-throwing side hip had significantly greater ER compared to the throwing side hip (p = 0.002). When examining side-to-side differences at the GHJ, IR was significantly greater in the non-throwing shoulder (p = 0.047). No significant differences in total range of motion of the hip and GHJ were observed.

Conclusion: In the current study, position players displayed side-to-side differences in hip and GHJ IR PROM while no statistically significant differences were observed in the softball pitchers. The findings of the current study add to the body of literature related to PROM in throwing athletes, additionally these are the first hip IR and ER PROM data presented in softball players.

Level of Evidence: Level 3

Key Words: pitchers; position players; throwing; upper extremity.

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INTRODUCTION

Throwing a softball overhead requires efficient coordination of both the lower and upper extremity for effective ball release.\(^1\) Fleisig\(^2\) describes the beginning of the throwing motion as the stride phase in which the non-throwing side or stride foot is pointed in the direction of the desired target. During the stride phase, the non-throwing side leg must have adequate hip external rotation (ER) in order to position the foot directly in line with the target. Proper non-throwing side leg (non-throwing side) positioning allows for optimal hip, pelvis and trunk position, for effective utilization of the kinetic chain to accelerate the ball during throwing.\(^3\) In addition, proper non-throwing side leg positioning also requires adequate hip internal rotation (IR) of the throwing side leg. Following the stride phase, the motion progresses into the cocking phase where the throwing arm must reach a position of maximum shoulder external rotation.

The final two phases of the throwing motion include arm acceleration (from maximum shoulder ER to ball release) and follow-through (ball release to maximum shoulder IR) phases. As the movement progresses into arm acceleration, hip ER of the throwing side leg is required to drive the body forward towards the target.\(^4\) After ball release, the body must decelerate the arm and this is best accomplished from the body rotating around the non-throwing leg, causing hip IR.

Due to the repetitive nature of overhead throwing, athletes participating in throwing sports often develop adaptive changes. An increase in ER and decrease in IR compared to the non-throwing arm is customary in baseball players.\(^5\) In addition, GHJ adaptive changes have been speculated to be due to a contracture of the posterior capsule and the inferior glenohumeral ligaments.\(^11\)\(^-\)\(^15\) as well as retroversion of the humeral head.\(^6\)\(^,\)\(^8\)\(^,\)\(^11\)\(^,\)\(^16\)\(^,\)\(^17\) These adaptive changes reported in baseball players have also been documented in collegiate softball players.\(^10\)\(^,\)\(^19\) However, in addition to examining the repetitive nature of overhead throwing in softball players, it is important to acknowledge that softball pitchers perform a unique underhand throw during the windmill softball pitch. The windmill softball pitch, just as the overhead throw requires both coordination and adequate range of motion (ROM) of both the lower and upper extremity for efficient ball release.\(^20\)

While it is evident that adaptations at the GHJ occur with repetitive throwing there is a lack of evidence on the adaptations that may occur at the hip, particularly in softball players. However, alterations in hip passive range of motion (PROM) have also been reported to be associated with upper extremity injury in throwing athletes.\(^21\)\(^,\)\(^22\) Reduced hip PROM throughout the throwing motion could result in alterations up the kinetic chain in effort to impart the same ball velocity at ball release. Deviations in hip PROM resulting in either throwing across the body (non-throwing side foot closed or directed more to the right for a right handed athlete) or opening up too early in the throw (non-throwing side foot directed more to the left of the desired target for a right handed athlete) will cause increased stress to not only the hip but also more distally in the upper extremity at the shoulder and elbow.\(^23\) Because these adaptations are not well understood, it is critical that research be conducted to describe both normal and abnormal hip PROM patterns.

The importance of PROM in throwing has been thoroughly examined in the sport of baseball\(^1\)\(^,\)\(^24\)\(^-\)\(^30\) however only a few studies have examined softball athletes.\(^10\)\(^,\)\(^19\)\(^,\)\(^31\) Of the aforementioned studies examining PROM in throwing athletes, only the baseball literature has focused on both the hip and GHJ, with the softball literature limited to only reports on glenohumeral PROM.\(^19\)\(^,\)\(^31\) As the number of injuries in softball players is on the rise, it is important to better understand GHJ and hip range of motion in these players. Therefore the purpose of this study was threefold: (1) to assess hip and GHJ PROM and total arc of motion in National Collegiate Athletic Association (NCAA) Division I softball players, (2) describe side-to-side differences in PROM of the hip and GHJ, and (3) compare hip and GHJ PROM between position players and pitchers.

METHODS

Participants

Participants were recruited from Auburn University’s softball team and were examined prior to beginning fall practice. Forty-nine NCAA Division I softball players (19.63 ± 1.15 years; 170.88 ± 8.08 cm; 72.96 ± 19.41 kg) participated. Participants included both pitchers (N = 10; 19.60 ± 0.97 years; 174.19 ± 9.97
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cm; 84.01 ± 10.34 kg) and position players (N = 39; 19.64 ± 1.20 years; 170.35 ± 7.30 cm; 70.13 ± 20.25 kg). Participant selection criteria included freedom from injury within the prior six months and being active on the playing roster. Auburn University’s Institutional Review Board approved all testing protocols. Prior to data collection all testing procedures were explained to each participant informed consent and participant assent was obtained.

**Procedures**

All participants were tested prior to the beginning of fall practices and had not thrown on the testing day, prior to their PROM measurements. A trained examiner, with clinical background as a certified athletic trainer, conducted all measurements. Bilateral hip and GHJ rotational PROM were measured using a Baseline Digital Inclinometer (Medline Industries, Mundelein, Illinois) (Figure 1 and 2). The average of three trials for each PROM measurement was used for analysis.

Hip rotational PROM (IR and ER) was measured with the participant in a seated position, knees flexed to 90° allowing the legs to comfortably hang off the edge of the table (standard athletic training treatment table) with their hands resting on the table to assist with trunk stabilization. The hip was positioned in 90° of flexion, by placing a towel under the femur and the digital inclinometer was aligned along the soft tissue contour of the participant’s tibia (Figure 1). The examiner supported the femur, to eliminate accessory motion, and passively rotated the hip until a capsular end-feel was achieved. At the point of a firm capsular end-feel without the production of accessory hip movement (hip hiking), the PROM measurement was recorded. The throwing side hip was defined as the ipsilateral hip to the throwing arm and the non-throwing side hip was contralateral to the throwing arm.

Glenohumeral IR and ER PROM measurements were performed with the participant supine. For the purposes of this study isolated GHJ motion was of main interest, therefore standard PROM techniques as well as a visual inspection technique to control for scapulothoracic movement were utilized. The visual inspection technique has been indicated to yield reliable measures for isolated glenohumeral motion. It is important to note that this method of measurement may result in lower observed PROM values than some previously published values in

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**Figure 1.** Hip passive range of motion.

**Figure 2.** Glenohumeral passive range of motion.
which researchers do not limit scapulothoracic movement. To perform the PROM measurements, participants were supine on the athletic training table with the arm elevated to 90° of abduction in the coronal plane and proximal humerus was supported with a towel to ensure neutral abduction/adduction in the transverse plane.25,29 For both IR and ER measurements, the digital inclinometer was supported against the soft tissue contour of the forearm between the olecranon process and the styloid process of the ulna. The examiner passively rotated the humerus in either IR or ER with one hand. The measurement was recorded when the scapula began to move (acromion process began to rise off of the table) or at a firm capsular end-feel.

The examiner reported excellent intra-rater reliability for both hip and GHJ in a pilot study of seven collegiate softball players (ICC(3,k) of 0.92 to 0.95 for all measurements). Minimal detectable change (MDC) values were calculated based on these pilot data in order to determine clinical significance for the measures. Any differences that are observed in the data must exceed the MDC to indicate a clinically significant change. Hip IR and ER PROM, MDC95 was 5.6° and 4.7°, respectively while glenohumeral joint IR and ER MDC95 values were 6.8° and 9.7°, respectively.

**Statistical Analysis**

Data were analyzed using IBM SPSS Statistics 20 (IBM corp., Armonk, NY).

A 2 (Throwing/Non-throwing) x 2 (IR/ER) x 2 (Hip/Shoulder) x 2 (Position/Pitcher) ANOVA was performed to examine differences in PROM between position players and pitchers. Total arc of motion measures, for the hip and GHJ, were calculated by summing the measurements for IR and ER. Separate paired samples t-tests were performed to evaluate IR, ER, and total arc of motion differences between the throwing and non-throwing side hip and GHJ in position players and pitchers. An alpha level of p < 0.05 was used to signal statistical significance.

**RESULTS**

Descriptive data for both hip and GHJ PROM are presented in Table 1. No significant differences in total arc ROM of the hip and glenohumeral joint were observed. The ANOVA revealed no significant interactions between pitchers and position players (F(1,47) = 3.705, p = 0.06). The paired samples t-tests revealed no significant side-to-side difference in hip and GHJ PROM in the pitchers, however there were significant side-to-side differences in the position players. In the sample of position players throwing side hip IR was significantly greater than the values observed for the non-throwing side hip (p = 0.002). For external rotation, the throwing side hip was significantly greater than the non-throwing side hip (p = 0.002). When examining side-to-side differences at the glenohumeral joint, IR was significantly greater in the non-throwing shoulder (p = 0.047) in this sample of position players.

Irrespective of the few statistically significant side-to-side differences that were observed, the current study also examined how many players had PROM differences greater than the MDC between the

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Pitches Throwing Side</th>
<th>Pitches Non-Throwing Side</th>
<th>Position Throwing Side</th>
<th>Position Non-Throwing Side</th>
<th>Combined Pitchers Throwing Side</th>
<th>Combined Pitchers Non-Throwing Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip IR</td>
<td>29.9 ± 7.8</td>
<td>31.5 ± 7.0*</td>
<td>35.7 ± 6.7</td>
<td>32.9 ± 7.4*</td>
<td>34.5 ± 7.3</td>
<td>32.6 ± 7.3</td>
</tr>
<tr>
<td>Hip ER</td>
<td>37.6 ± 10.2</td>
<td>38.2 ± 7.3</td>
<td>39.7 ± 8.0</td>
<td>42.1 ± 8.1</td>
<td>39.3 ± 8.4</td>
<td>41.3 ± 8.0</td>
</tr>
<tr>
<td>Hip Total PROM</td>
<td>67.5 ± 16.5</td>
<td>69.7 ± 11.3</td>
<td>75.4 ± 11.7</td>
<td>75.0 ± 13.7</td>
<td>73.8 ± 13.0</td>
<td>73.9 ± 13.3</td>
</tr>
<tr>
<td>Glenohumeral IR</td>
<td>39.3 ± 9.0</td>
<td>38.3 ± 11.2</td>
<td>33.9 ± 9.6*</td>
<td>36.7 ± 8.2*</td>
<td>35.0 ± 9.6</td>
<td>37.0 ± 8.8</td>
</tr>
<tr>
<td>Glenohumeral ER</td>
<td>100.7 ± 8.9</td>
<td>100.0 ± 10.3</td>
<td>98.9 ± 12.6</td>
<td>97.5 ± 8.6</td>
<td>99.3 ± 11.9</td>
<td>98.0 ± 8.9</td>
</tr>
<tr>
<td>Glenohumeral Total PROM</td>
<td>140.0 ± 9.7</td>
<td>138.2 ± 9.8</td>
<td>132.9 ± 15.4</td>
<td>134.2 ± 12.5</td>
<td>134.3 ± 14.6</td>
<td>135.0 ± 12.0</td>
</tr>
</tbody>
</table>

+ = significant difference between positions at p≤0.05.
* = significant side to side difference at p≤0.05.
dominant and non-dominant sides (Table 2). This was examined in order to look for clinically significant differences.

**DISCUSSION**

The current study examined hip and GHJ rotational PROM in NCAA Division I softball pitchers and position players to determine if side-to-side differences were present. With the increase in injuries in softball players, descriptions of PROM in collegiate softball players are needed to allow clinicians working with these athletes to better understand potential motion restrictions that these players may have. Understanding PROM deficits could potentially lead to enhanced training and rehabilitation protocols that address these deficiencies. Side-to-side differences were not observed in the pitchers which may have been due to the small portion of the sample comprised of pitchers. When examining the position players, side-to-side differences were observed at the shoulder, with greater IR in the non-throwing arm compared to the throwing arm. Despite the statistically significant differences found in the current study, these differences were small and failed to surpass the calculated MDC95 value of 6.8°. These results are in partial agreement with those of Shanley et al. who did not observe any significant differences in PROM in the high school softball players that they studied. However, the data presented by Shanley et al. likely included some of the players that had asymmetric PROM differences that when grouped in a larger sample were not statistically different.

Further expanding on the analyses, the number of players with side-to-side differences exceeding the MDC for glenohumeral IR were examined in attempt to identify those lacking symmetry and thus possible candidates for intervention programs. Some position players (12/39) and pitchers (2/10) had side-to-side differences in GHJ IR that were clinically significant. The results of this study are a valuable reminder to sports medicine clinicians working with softball players when examining PROM that some players may not have side-to-side patterns consistent with that reported in the literature. It has been speculated that baseball players with deficits in GHJ internal rotation deficits may be at greater risk for upper extremity injury and it is possible that this may also be true for softball. Each player’s PROM deficit should be addressed and some players may warrant targeted mobility interventions.

Irrespective of the significant IR side-to-side difference, there was no total arc of motion difference between the throwing and non-throwing arm. The lack of significant change in total arc of motion indicates that while GHJ IR may have decreased there was a concomitant increase in ER leading to similar total arc of motion between sides. This may be supported by the current results that some position players and pitchers had side-to-side differences in GHJ ER that surpassed the MDC (9.7°). These GHJ PROM data for the position players are consistent with those values from both the baseball and softball literature (Table 3). Previous literature has postulated that this shift in arc of motion may be a protective mechanism. The symmetrical shift in ROM could potentially alleviate stress on the anterior-inferior GHJ capsule as well as maximize throwing velocity.

In addition to the GHJ PROM, this study also examined PROM profiles of the hip in both softball pitchers and position players. The importance of hip PROM and strength in overhead throwers has previously been established.

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**Table 2. Number of position players and pitchers exceeding the minimal detectable change for each range of motion measure.**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>MDC95 Indicating Clinical Significance</th>
<th>Position Players Exceeding MDC95</th>
<th>Pitchers Exceeding MDC95</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip IR</td>
<td>5.6°</td>
<td>16/39 (41.0%)</td>
<td>2/10 (20.0%)</td>
</tr>
<tr>
<td>Hip External</td>
<td>4.7°</td>
<td>8/39 (20.5%)</td>
<td>5/10 (50.0%)</td>
</tr>
<tr>
<td>Glenohumeral IR</td>
<td>6.8°</td>
<td>12/39 (30.8%)</td>
<td>2/10 (20.0%)</td>
</tr>
<tr>
<td>Glenohumeral ER</td>
<td>9.7°</td>
<td>11/30 (36.7%)</td>
<td>4/10 (40.0%)</td>
</tr>
</tbody>
</table>
energy generation and transfer from the lower extremity to the upper extremity in overhead throwing, the lower extremity should supply 50% of the total kinetic energy during the throw. The more efficient the body can work as a kinetic chain from the lower extremity to the upper extremity, the more optimal the outcome. In overhead throwing, proper hip and pelvis orientation at foot contact requires adequate IR of the throwing side hip and ER of the non-throwing side hip for the trunk to square to the target. Then after ball release, to dissipate energy, the body should rotate around the non-throwing side hip resulting in throwing side hip IR. Asymmetric hip loading patterns are present in baseball pitching and it is expected that sport-specific and extremity-specific range of motion adaptations are likely to occur in all overhead throwing motions. Ellenbecker et al. previously examined hip IR and ER ROM in professional baseball pitchers. Internal rotation in the pitchers throwing hip was \(23 \pm 8.3^\circ\) and \(22 \pm 8.9^\circ\) in the non-throwing hip. IR of the throwing hip is necessary to position the non-throwing stride leg. Limited IR of the throwing hip may lead to a player throwing across their body while limiting the use of energy from the lower extremity. In the current study, greater throwing side hip IR was observed in position players but this difference was not clinically significant. Therefore, we also examined the number of players with side-to-side differences that were clinically significant. Forty-one percent (41%) of position players had clinically significant IR differences between their throwing and non-throwing side hips and 21% had clinically significant differences in hip ER.

The results of this study provide valuable data on hip and GHJ PROM rotational profiles in NCAA Division I softball players, which have not been previously reported. While this study provides valuable descriptive glenohumeral and hip PROM values it is important to note that limitations do exist. The data for this study were collected on players from only one NCAA Division I Softball Team. It is possible that these data are not generalizable to PROM in other teams and in larger samples of softball pitchers. There are many factors that must be accounted for when examining PROM data such as previous injury, team and individual training and rehabilitation programs, and pre-competition warm-up routines. Some softball programs may place greater emphasis on thorough pre and post throwing stretching protocols than other programs thereby greatly influencing the players’ PROM. In effort to account for this the researchers collected data at the beginning of the fall academic semester prior to any individual or team training that may have occurred. Furthermore, it is important to note that the small sample size of pitchers may have contributed to the lack of significant differences in range of motion. Future research should examine hip and GHJ PROM in a larger number of NCAA Division I softball players across multiple teams to determine if these values are similar. Additionally, in depth analysis of the effects of PROM on throwing kinematics in softball players should also be examined to better understand the role hip PROM has on the efficiency of the kinetic chain.

### CONCLUSIONS

The results of this study demonstrated statistically significant PROM differences in hip IR between pitchers and position players and side-to-side differences in GHJ IR in position players. However these differences were small and did not achieve the minimal detectable change threshold for clinical significance.
Regardless of statistical or clinical significance the descriptive data presented in this study can serve as a baseline for future research. The amount of shoulder and hip PROM in softball players likely has a major role in their ability to maximize throwing and pitching velocity through sequential kinetic chain sequencing. Examining these measures in softball players and subsequently monitoring these data longitudinally can allow for individual training programs to be created based on PROM limitations.

REFERENCES


ABSTRACT

Background: Clinical examination of capsuloligamentous structures of the glenohumeral joint has historically been subjective in nature, as demonstrated by limited intra-rater and inter-rater reproducibility. Musculoskeletal diagnostic ultrasound was utilized to develop a clinically objective measurement technique for glenohumeral inferior and posterolateral translation.

Purpose: The purpose of this study was to measure the accessory passive force required to achieve end range glenohumeral posterolateral and inferior accessory translation, as well as, to quantify the amount of translation of the glenohumeral joint caused by the applied force.

Study Design: Cross-sectional descriptive correlational study

Methods: Twenty-five asymptomatic subjects between the ages of 18 and 30 were recruited via convenience sampling. Posterolateral and inferior shoulder accessory passive translation was assessed and measured using a GE LOGIQe ultrasound, while concurrently using a hand held dynamometer to quantify the passive force applied during assessment. Normative values for force and translation were described as means and standard deviations.

Results: Mean values for posterolateral translation were 6.5 +/- 4.0 mm on the right shoulder and 6.3 +/- 3.5 mm on the left with an associated mean force of 127.1 +/- 55.6 N and 114.4 +/- 50.7 N, respectively. Mean values for inferior translation were 4.8 +/- 1.7 mm on the right shoulder and 5.4 +/- 1.8 mm on the left with an associated mean force of 84.5 +/- 30.5 N and 76.1 +/- 30.1 N, respectively. There was a significant association between inferior translation and inferior force (r=.51). No significant association was found between posterolateral translation and posterolateral force. Significant differences were found between dominant and non-dominant shoulders for posterolateral translation, posterolateral force to produce translation, and inferior translation values.

Conclusions: Force data in the posterolateral and inferior direction is consistent with previously reported data for passive accessory motion testing at the shoulder. The results of this study provide data for glenohumeral translations and actual forces applied. Musculoskeletal diagnostic ultrasound can be a clinically relevant way to objectively measure the translation of the glenohumeral joint for assessing accessory passive motion joint translation while performing mobilizations or passive structure testing. This study provides a basis for comparison for healthy shoulder joints.

Level of Evidence: 2b

Keywords: Diagnostic ultrasound, glenohumeral joint translation, handheld dynamometry

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INTRODUCTION
Optimal shoulder function depends on adequate stability and mobility of active and passive joint structures. The rotator cuff acts as the primary active stabilizer by compressing the humeral head in the glenoid fossa. The glenoid labrum and capsuloligamentous structures provide the primary passive restraints to excessive glenohumeral (GH) motion. The objective examination of strength of the active stabilizers has been well established in the literature and can be reliably measured by use of dynamometry, electromyography, and isokinetics. However, clinical examination of capsuloligamentous structures has historically been subjective in nature, as demonstrated by limited intra-rater and inter-rater reproducibility.

Several methods have been used in an attempt to objectify GH translation including computed tomography, stress radiograph, electromagnetic spatial tracking (EST), and linear displacement transducers (LDT). However, these assessment tools are not readily available in clinical practice for the rehabilitation professional. Musculoskeletal diagnostic ultrasound is a non-invasive, easy to use and portable modality. It has been shown to be a reliable and valid modality for assessing GH translation in the anterior, inferior, and posterior direction.

Regardless of imaging modality, a wide range of GH translations have been reported in asymptomatic subjects and athletes. A portion of the variability is likely due to the varied shoulder testing positions, the magnitude of forces used for GH accessory mobility assessment, and the techniques of measurements. Various testing positions produced differences in end range GH translation distances (Table 1).

Several authors have demonstrated a linear relationship between amount of translation and magnitude of force. ultrasound to measure the amount of posterolateral (PL) and inferior joint translation with respect to the magnitude of force applied.

The purpose of this study was to measure the accessory passive force required to achieve end range GH PL and inferior accessory translation. Quantifying the external force applied to the GH joint during accessory passive motion testing to reach end-range is important to clinicians in order to document the degree of translation. It is hypothesized there would be a correlation between GH accessory passive translation distance and magnitude of force applied.

MATERIALS AND METHODS
Subjects
This study used a convenience sample of 25 healthy college-aged students (9 males, 16 females; mean age 26 years; mean height and weight 1.7 m and 72 kg, respectively). Females comprised 64% of the sample and all participants were right hand dominant. Sixteen percent of the participants had participated at a competitive level in an overhead sport for at least one year of competition (Table 2).

Exclusion criteria included a history of upper extremity injury, shoulder surgery, and/or presence of shoulder pain. Participants were measured bilaterally, with each shoulder representing an individual data point. Subjects were provided with detailed information regarding study procedures and any risk associated with the study protocol. The study was approved by the Institutional Review Board at Armstrong State University. All subjects gave written informed consent prior to study participation.

Upon volunteering, subjects completed an intake screening form and a demographic questionnaire to determine eligibility for participation in the study.

Ultrasound Imaging
Subjects were positioned supine on a treatment plinth, with the shoulder positioned in 60° of abduction and neutral GH rotation. Previous research has demonstrated that considerable amounts of GH laxity exists in all directions at 60° of abduction. The direction of GH translation (inferior v. PL) was randomly assigned before each assessment.
<table>
<thead>
<tr>
<th>Reference</th>
<th>Imaging Technique</th>
<th>Upper Extremity Position</th>
<th>Force (N)</th>
<th>Average Translation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sauers et al</td>
<td>LDT</td>
<td>20° Abduction</td>
<td>67</td>
<td>Anterior=7.5, Posterior=9.3</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>89</td>
<td>Anterior=8.9, Posterior=10.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>111</td>
<td>Anterior=10.2, Posterior=11.8</td>
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<td></td>
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<td>134</td>
<td>Anterior=11.3, Posterior=12.7</td>
</tr>
<tr>
<td>Borsa et al</td>
<td>LDT</td>
<td>20° Abduction</td>
<td>67</td>
<td>Anterior=6.1, Posterior=5.0</td>
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<td>Anterior=7.4, Posterior=6.1</td>
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<tr>
<td>Karup et al</td>
<td>US</td>
<td>0° Abduction</td>
<td>89</td>
<td>Anterior=1.9</td>
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<tr>
<td>Court-Pyen et al</td>
<td>US</td>
<td>0° Abduction, Internal Rotation</td>
<td>90</td>
<td>Anterior=1.8</td>
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<td>Ellenbecker et al</td>
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<td>Harryman et al</td>
<td>EST</td>
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<td>Stress Radiograph</td>
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<td>90° Abduction, 60° ER</td>
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<td>US</td>
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<td>Stress Radiograph</td>
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<td>Inferior=4.7</td>
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<tr>
<td>Cheng et al</td>
<td>US</td>
<td>90° Abduction, 10° Extension</td>
<td>Force to End Feel</td>
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<td>Tibone et al</td>
<td>EST</td>
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<td>Dominant Shoulder=9.6</td>
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<td>Non-Dominant Shoulder=10.7</td>
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<td>EST</td>
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<td>203</td>
<td>Anterior=14.5</td>
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<td>Inferior=13.9</td>
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<td>Talbott et al</td>
<td>US</td>
<td>55° Abduction, 30° Horizontal Adduction, 0° Rotation</td>
<td>41.7</td>
<td>Posterior=3.0</td>
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<td>Posterior=8.2</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>209.4</td>
<td>Posterior=10.7</td>
</tr>
</tbody>
</table>

LDT=Linear displacement transducer, US= ultrasound, EST= electromagnetic spatial trackers
Ultrasound imaging was obtained using a GE LOGIQe unit (GE Healthcare, Milwaukee, Wisconsin) with a 3.96-8.41 MHz transducer by an examiner with 16 hours of training with the specific technique used in this study and over three years of experience using ultrasound imaging clinically. Palpation was used to locate the coracoid process and greater tuberosity, according to previously described procedures.\textsuperscript{16,18,19} The transducer was placed horizontally over the anterior aspect of the glenohumeral joint, just anterior and inferior to the acromion (Figures 1, 2). Two bony landmarks were identified on the ultrasound image: the

![Figure 1](image)

**Figure 1.** Depiction of ultrasound transducer and HHD positioning during application of inferior force.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects, n</td>
<td>25</td>
</tr>
<tr>
<td>Age, years</td>
<td>26.1 (22-35)</td>
</tr>
<tr>
<td>Height</td>
<td>1.7 m</td>
</tr>
<tr>
<td>Weight</td>
<td>72 kg</td>
</tr>
<tr>
<td>Sex, %</td>
<td>36</td>
</tr>
<tr>
<td>Male</td>
<td>64</td>
</tr>
<tr>
<td>Right hand dominant</td>
<td>100</td>
</tr>
<tr>
<td>Left hand dominant</td>
<td>0</td>
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<td>Overhead sport, %</td>
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<tr>
<td>“Yes” to participation</td>
<td>16</td>
</tr>
<tr>
<td>“No” to participation</td>
<td>84</td>
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</tbody>
</table>

M= meters; kg= kilograms; %= percentage of the sample
superior surface of the coracoid process and the most superior aspect of the humeral head. Care was taken to include the greater tuberosity to allow consistent landmark identification when measuring translation distance after data collection. After adequate visualization of bony landmarks, a resting image was obtained. Resting images were immediately inspected and repeated if adequate visualization was not achieved.

**GH Passive Accessory Motion Testing**

After resting images were obtained, a hand held dynamometer (HHD), (Layfayette Manual Muscle Tester Model 01163®, Layfayette, IN), was placed as close to the GH joint as possible without disrupting the ultrasound transducer. An inferior or PL passive accessory force was performed until a firm capsular end feel was noted by a second examiner with over 40 years of experience of teaching and treating patients using GH joint mobilizations. A PL passive force was utilized due to the orientation of the glenoid fossa. Force was applied through the HHD until a normal, firm capsular end feel was obtained. Each passive accessory motion was completed in approximately one second. At this time, ultrasound landmarks were confirmed again and a second image was captured. Translation forces were blindly recorded by a third examiner. This sequence was repeated three times in each direction on each shoulder, for a total of six pairs of ultrasound images per subject. The mean of the three measurements on each shoulder was used for data analysis.

**Measurement**

After data collection, the acquired images were reviewed and measured using the ultrasound's built-in measuring tools. For PL translation, a horizontal line was placed on the screen in line with the superior aspect of the coracoid process. The distance between this horizontal line and the most superior aspect of the humeral head was then measured. This value represented the anterior-posterior distance between the greater tuberosity and the coracoid process (Figures 1 and 2). A similar process was undertaken for inferior translation. The superior-inferior distance between the superior aspect of the coracoid process and the superior aspect of the humeral head was measured. The difference in distance between the resting and passive translation images was the amount of total GH translation (Figures 3 and 4). This procedure was repeated for each pair of images. Mean translation distance (three trials of inferior and PL), measured in millimeters (mm), as well as, the mean newtons of force (N) was used for data analysis.

*Figure 2. Depiction of ultrasound transducer and HHD positioning during application of posterolateral force.*
conducted to assess differences in translation and force values between gender and dominant versus nondominant shoulders. In the event that data was not normally distributed, a Wilcoxin Signed Rank test was used to assess between group differences. Alpha was set at 0.05. Scatterplots assessed linear relationships between PL and inferior translation with amount of force. Correlations between translatory motion and force were assessed using

Data analysis
Descriptive statistics were calculated for age, gender, hand dominance, and participation in overhead sports. ICCs (model 2) were calculated to assess intra-rater reliability for PL and inferior force. PL and inferior translation distances were reported as mean values, in millimeters, and standard deviations. Normality was assessed using a Shapiro-Wilk test and histograms. Dependent samples t-tests were conducted to assess differences in translation and force values between gender and dominant versus nondominant shoulders. In the event that data was not normally distributed, a Wilcoxin Signed Rank test was used to assess between group differences. Alpha was set at 0.05. Scatterplots assessed linear relationships between PL and inferior translation with amount of force. Correlations between translatory motion and force were assessed using

Figure 3. Image 1. Anterior transverse view of the ultrasound image demonstrating the starting position for posterolateral accessory translation: (1) Superior most aspect of humeral head (2) Superior aspect of coracoid process.

Figure 4. Image 2. Anterior transverse view of the ultrasound image demonstrating the end position for posterolateral accessory translation: (1) Superior aspect of humeral tuberosity (2) Superior aspect of coracoid process.

Figure 5. Image 3. View of the ultrasound image demonstrating the starting position for inferior accessory translation: (1) Superior aspect of humeral tuberosity (2) Superior aspect of coracoid process.

Figure 6. Image 4. View of the ultrasound image demonstrating the end position for inferior accessory translation: (1) Superior aspect of humeral tuberosity (2) Superior aspect of coracoid process.
Pearson Correlation Coefficients. The following classification was used to interpret the strength of correlation between measures: +/- .1 = weak correlation, +/- .3 = moderate correlation, +/- .5 = strong correlation.27 All analyses were completed using SPSS version 21.

RESULTS
Analyses yielded coefficient values of 0.78 for PL force and 0.93 for inferior force for intra-rater reliability, indicating good-excellent reliability. The following correlational analyses were examined in this study: inferior translation with inferior force and PL translation with PL force. There was a significant association between inferior translation and inferior force demonstrating a strong correlation (r = .51; p = 0.00). No significant association was found between PL translation with PL force. (Table 7)

The sample means for PL force, translation, and force per translation are presented in Table 3. Table 4 displays sample means for inferior force, translation, and force per translation.

Dependent samples t-tests demonstrated significant differences between dominant and nondominant shoulders for both PL force and translation. (Table 5) There was a significant difference in mean values for force required to produce inferior translation between dominant and nondominant shoulders, with the dominant shoulder requiring greater force to produce inferior translation compared to the nondominant side. Additionally, males required a statistically greater amount of force to glide inferiorly when compared to females. Inferior translation values were statistically similar between males and females and dominant and nondominant shoulders. (Table 6)

DISCUSSION
The purpose of this study was to measure the accessory passive force required to achieve end range GH PL and inferior translation. It was hypothesized there would be a correlation between GH accessory

<table>
<thead>
<tr>
<th>Table 3. Mean Values for Posterolateral Force and Translation (Reported as means +/- SD's)</th>
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<tbody>
<tr>
<td><strong>Mean Force</strong></td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
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<tr>
<td>Total Sample</td>
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<tr>
<td>Males</td>
</tr>
<tr>
<td>Females</td>
</tr>
<tr>
<td>Right shoulder</td>
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<tr>
<td>Left shoulder</td>
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</tbody>
</table>

N= newtons of force, mm= millimeters of humeral head translation, force/translation= amount of force per millimeter of movement

<table>
<thead>
<tr>
<th>Table 4. Mean Values for Inferior Force and Translation (Reported as means +/- SD's)</th>
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</thead>
<tbody>
<tr>
<td><strong>Mean Force</strong></td>
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<tr>
<td>---------------------------------------------------------------</td>
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<tr>
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<tr>
<td>Left shoulder</td>
</tr>
</tbody>
</table>

N= newtons of force, mm= millimeters of humeral head translation, force/translation= amount of force per millimeter of movement
passive translation distance and magnitude of force applied. This hypothesis was partially supported by the results.

The average value for posterolateral translation in the current study was 6.4 mm, when the humerus was positioned at 60° of abduction, which compares favorably to previous work by Borsa et al, who demonstrated mean values ranging from 3.97-5.94 mm in GH positions of 60 and 90° of abduction.14,15,25 Inferior translation of 5.1 mm found in the current study was consistent with Cheng et al who measured 4.7 mm, however varied from Borsa et al of 13.9 mm of inferior translation.13,16 This variation was possibly due to Borsa et al using a position of limited shoulder abduction (0-20 degrees) as opposed to the position of 60° of abduction used in the current study, which may have selectively tightened the inferior capsule and inferior GH ligaments which would contribute to the decreased inferior translation.13 This supposition is supported by findings of Hsu et al who demonstrated a decrease in inferior translation as the GH joint was taken into higher ranges of abduction.23

The average PL force used in the current study to achieve full glide was 121 N, measured at 60º of abduction. This value was less than the value of 191N, found in the study by Borsa et al,13 measured at 20º of abduction. This difference may have been due to Borsa et al utilizing a custom built stress device, whereas the current study used direct manual contact to apply the force to replicate clinical conditions. A custom built stress device may allow force to the GH joint that is not possible with methods used clinically. T albott et al used a similar testing set up to the current study and found that 209 N of posterior force was used to create a grade III mobilization, defined as the point in posterior shoulder

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### Table 5. Between Group Differences for Dominant and Non-Dominant Shoulders

<table>
<thead>
<tr>
<th>Variable</th>
<th>t-test statistic</th>
<th>Mean difference</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterolateral Force</td>
<td>3.19</td>
<td>12.8 +/- 20.0 N</td>
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</tr>
<tr>
<td>Inferior Force</td>
<td>5.54</td>
<td>8.4 +/- 7.5 N</td>
<td>0.00</td>
</tr>
<tr>
<td>Posterolateral Translation</td>
<td>0.16</td>
<td>1.4 +/- 4.4 mm</td>
<td>0.88</td>
</tr>
<tr>
<td>Inferior Translation</td>
<td>1.4</td>
<td>5.0 +/- 1.8 mm</td>
<td>0.16</td>
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</tbody>
</table>

N= newtons, mm=millimeters

### Table 6. Between Group Differences for Gender

<table>
<thead>
<tr>
<th>Variable</th>
<th>t-test statistic</th>
<th>Mean difference</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterolateral Force</td>
<td>2.17</td>
<td>23.0 +/- 45.0 N</td>
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</tr>
<tr>
<td>Inferior Force</td>
<td>3.01</td>
<td>17.6 +/- 24.9 N</td>
<td>0.01</td>
</tr>
<tr>
<td>Posterolateral Translation</td>
<td>0.05</td>
<td>0.1 +/- 5.4 mm</td>
<td>0.96</td>
</tr>
<tr>
<td>Inferior Translation</td>
<td>1.49</td>
<td>0.6 +/- 1.8 mm</td>
<td>0.16</td>
</tr>
</tbody>
</table>

N=newtons, mm=millimeters

### Table 7. Correlation Values between Force and Translation

<table>
<thead>
<tr>
<th>Variables</th>
<th>p-value</th>
<th>Correlation Coefficient (r-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inferior force with Inferior translation</td>
<td>0.00*</td>
<td>0.51</td>
</tr>
<tr>
<td>Posterior force with Posterior translation</td>
<td>0.10</td>
<td>0.49</td>
</tr>
</tbody>
</table>

*p value <.05; two-tailed test
mobilization where all tissues were taut and resistance to movement rapidly increased. These results highlight the overall poor interrater reliability of providers when assessing joint accessory motion. According to a 2014 systematic review, inter-clinician reliability was moderate to poor with force application during mobilization of the cervical, lumbar, and tibiofemoral joint (ICC = -0.04 to 0.70). To date, no studies have demonstrated acceptable levels of interrater reliability for accessory motion testing of the GH joint. Previous authors have demonstrated that posterior translation increases as the GH joint is moved into higher ranges of abduction. The average inferior force was 80 N in the present study, which was less than the value of 181 N found by Borsa et al. However, this difference again may be attributed to differences in measurement technique and shoulder position between studies.

No significant correlation was found between the amount of PL force applied and the amount of shoulder PL translation. There are a few possible explanations for the lack of correlation between force applied and translation distance measured. Muscle guarding during GH translation has been described previously and may have been increased during the examination due to the pressure from the HHD on the bicipital groove compressing the underlying soft tissue. The compression may have caused pain and increased muscle guarding. Previous authors have examined the effects of capsuloligamentous stiffness on translation and found a linear relationship, indicating that stiffness or guarding increased as the amount of translation increased. The HHD was required to be placed slightly distal on the humerus due to the ultrasound probe positioning needed to concurrently assess the GH joint translation. Moving the site of force application away from the GH joint may have decreased the amount of force imparted on the joint, thus decreasing the amount of total GH translation. Future studies may utilize a curved attachment for the HHD to decrease direct pressure exerted on the biceps groove/tendon. Also, shoulder translations were performed at 60 degrees of abduction, as this is the commonly reported open packed position for the GH joint. Lin et al noted an average open packed position of 23.7 ± 8.4 degrees of abduction when measuring GH joint translation in a group of 15 healthy subjects with an average age of 23. This calls into question the ability to generalize 60 degrees of GH abduction as an open packed position of the shoulder in a group of young healthy subjects, similar to the subjects in the study. Deviation away from a subject’s true open packed position would likely limit GH translation due to capsular tightening.

There was a significant correlation between the amount of inferior force applied and the distance of shoulder inferior translation. Therefore, as more force was applied in an inferior direction, a greater amount of translation of the GH joint was observed. This may be due to the location of force application being in a less sensitive area of the shoulder when compared to the area of force application with PL translation.

Although not specifically an aim of the current study, it was noted that a greater amount of force was required to attain the same amount of GH translation in male subjects as compared to female subject. This is in agreement with Talbott et al, who also found a higher force required to achieve grade III posterior translation in the shoulder of male subjects when compared to female subjects. This may be due to increased guarding in male subjects or increased force needed to induce accessory movements due to muscle mass. EMG was not used for assessment of the surrounding musculature, so the exact cause of the increased force required between sexes could not be determined in the current study. The role of muscle contraction during GH translation may be an important area for future research.

Previous authors have found that shoulder translation distances are decreased in pathological shoulders as compared to their uninvolved shoulders. Posterior mobilization of the GH joint is a commonly utilized clinical technique to evaluate and improve the accessory motion and positively affect range of motion of internal rotation, flexion, and adduction. Inferior mobilizations are used to evaluate and improve the accessory motion and range of motion for overhead motions. Harryman et al found that asymptomatic shoulders demonstrated a wide range of translation on clinical testing, with ranges of 19mm (3-22mm) for posterior drawer testing and 10mm (5-15mm) for sulcus testing. The wide range of normal GH joint translation should be considered when evaluating the amount of translation for individual subjects and may limit the generalizability of GH translation studies with small sample sizes. Future research should
assess the amount of translation and amount of force during accessory motions on symptomatic subjects. It may also be worthwhile to investigate the relationship between GH joint translation and physiologic passive range of motion in subjects with pathology.

Several limitations should be noted. An experienced clinician performed the application of force, as would be done in a clinical setting, as compared to a custom-built force application device, indicating there could have been a non-uniform rate of force application. Additionally, visualizing bony landmarks with the ultrasound was sometimes difficult due to soft tissue compression that occurred during application of the passive force. Intrarater reliability of the ultrasound measurements of GH translation was not performed prior to the current study. Although this is a limitation, the intrarater and interrater reliability has been well established in the literature (ICC 0.946 and 0.89-0.964.7 respectfully), as well as the validity of this measure as compared with stress radiography.1416 Lastly, since this study only used healthy subjects, the results cannot be generalized to a pathological population.

CONCLUSION
Average PL translation of 6.3 mm and average inferior translation of 6.1 mm were found in healthy subjects at 60° of abduction. The average PL force was 120 N and inferior force was 80 N. There were significant differences found between dominant and non-dominant shoulders for PL translation, PL force to produce translation, and inferior translation values. Additionally, males required greater force than females for inferior translation. There were no significant correlations found between PL force and PL translation. However, there was a significant correlation between inferior force and inferior translation. This information can aid in assessment and treatment by providing baseline values for PL and inferior translations directions. The results indicate that musculoskeletal diagnostic ultrasound can be a clinically relevant way to objectively measure the translation of the GH joint for assessing accessory passive motion joint translation while performing mobilizations or passive structure testing.

REFERENCES


CORRECTED ERROR VIDEO VERSUS A PHYSICAL THERAPIST INSTRUCTED HOME EXERCISE PROGRAM: ACCURACY OF PERFORMING THERAPEUTIC SHOULDER EXERCISES

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Jennifer Hopp, MD5
Laura Stanley, DPT6
Ken Spores, DPT8
David Braunreiter, MD6,7

ABSTRACT

Background and Purpose: The accurate performance of physical therapy exercises can be difficult. In this evolving healthcare climate it is important to continually look for better methods to educate patients. The use of handouts, in-person demonstration, and video instruction are all potential avenues used to teach proper exercise form. The purpose of this study was to examine if a corrected error video (CEV) would be as effective as a single visit with a physical therapist (PT) to teach healthy subjects how to properly perform four different shoulder rehabilitation exercises.

Study Design: This was a prospective, single-blinded interventional trial.

Methods: Fifty-eight subjects with no shoulder complaints were recruited from two institutions and randomized into one of two groups: the CEV group (30 subjects) was given a CEV comprised of four shoulder exercises, while the physical therapy group (28 subjects) had one session with a PT as well as a handout of how to complete the exercises. Each subject practiced the exercises for one week and was then videotaped performing them during a return visit. Videos were scored with the shoulder exam assessment tool (SEAT) created by the authors.

Results: There was no difference between the groups on total SEAT score (13.66 ± 0.29 vs 13.46 ± 0.30 for CEV vs PT, p = 0.64, 95% CI [-0.06, 0.037]). Average scores for individual exercises also showed no significant difference.

Conclusion/Clinical Relevance: These results demonstrate that the inexpensive and accessible CEV is as beneficial as direct instruction in teaching subjects to properly perform shoulder rehabilitation exercises.

Level of Evidence: 1b

Keywords: Exercises, shoulder, physical therapy, video

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INTRODUCTION
Developing effective methods to communicate patient instructions can prove beneficial in ensuring adherence and optimal outcomes to prescribed therapies.\(^1\) The field of physical therapy relies heavily on patients regularly and accurately performing home exercise routines.\(^2,3\) For these routines to be successful, information about proper exercises, techniques, and frequency must be reliably relayed from provider to patient. Given that medical literacy is a critical determinant of health care outcomes,\(^4,5,6\) identifying reliable ways to impart educational concepts to patients remains an important goal.

The earliest research on substitutes for direct teaching utilized brochures that displayed, either in verbal or pictorial format, exercise instructions and schedules.\(^7,8\) In both of these studies, subjects receiving direct therapist instructions performed better than those who were taught by a brochure, suggesting that more effective methods of communication are needed to substitute for direct one-on-one interaction. Subsequent research has focused on the use of video recordings for patient instruction. The authors found that using videotape was at least as effective as direct teaching,\(^9\) if not more effective,\(^10,11\) in instructing subjects to accurately perform exercises.

All of the above examples used videos that demonstrated the “correct” method of performing an exercise. However, it is well established that knowing the incorrect method of performing a task, or how an incorrectly performed task can be rectified, can improve learning.\(^12,13,14,15\) Given this, developing a video demonstration that not only displayed the correct method of performing an exercise, but also common incorrect methods, may prove as effective as in-person teaching in communicating information to subjects. Such video demonstrations are termed corrected error videos (CEV). Reo and Mercer examined whether CEV could be used to teach upper-extremity exercises.\(^11\) They tested subjects in one of four instruction methods: live instruction, CEV, error-free video, and handout. They found that, 24hrs following instruction, no difference in performance (rated using a checklist of critical criteria for each exercise) was found between subjects taught using CEV, error-free video, or live instruction.\(^11\) These results suggest that, at least in the short-term and for a particular video, CEV is as effective as live instruction. However, to date, longer-term retention of instruction has not been explored.

The purpose of this study was to examine if a corrected error video (CEV) would be as effective as a single visit with a physical therapist (PT) to teach healthy subjects how to properly perform four different shoulder rehabilitation exercises. The hypothesis was that the CEV would be as effective as direct instruction in teaching healthy subjects four shoulder rehabilitation exercises—scapular retraction, external rotation with elastic resistance, internal rotation with elastic resistance, and the standing row with elastic resistance.

METHODS
Subjects were recruited at two independent institutions, the University of North Carolina (UNC) and Houston Methodist (HM). Inclusion criteria included no prior history of shoulder pathology, fluency in English, and daily access to and proficiency in using a DVD player. Exclusion criteria included dementia or cognitive disability, vision or hearing impairments, or pregnancy. Subjects with a self-reported history of receiving formal physical therapy training in the past year or experience with study exercises were also excluded. At both institutions, randomization was done using standard block randomization in blocks of four.

At UNC, 30 subjects ranged from 18 to 25 years of age (average age = 21.2, SD = 3.7; 11 male and 19 female). Subjects were recruited from the student body and campus. Sixteen were randomized into the CEV group and 14 into the physical therapy (PT) group. Two subjects, both in the PT visit group, were excluded from analysis because one subject did not return for follow-up evaluation and one had pain while performing the exercises and chose not to return. In addition, two subjects in the CEV group were excluded from the analysis: these subjects were inadvertently not informed which exercises on the disc to complete (the DVD contained more than just the four shoulder exercises used in the study). It should be noted that their exclusion did not alter the statistical significance of any of the results. At the completion of the study, there were 14 CEV subjects and 12 PT subjects from this institution.
At HM, 35 subjects were recruited into the study. Subjects from this site were recruited from the hospital staff. Nineteen subjects were randomized into the CEV group, while 16 were included in the PT group. Three subjects, all in the CEV group, were removed from the study: two subjects suffered unrelated injuries and were not able to complete the study, and a third could not meet the time commitment. Ultimately, 32 subjects ranging from 28 to 66 years of age (average age 42.2, SD = 11.3; 7 male and 25 female) were randomized with 16 in the CEV group and 16 in the PT group. A consort diagram diagramming the outcomes of subjects (n = 58) recruited is shown in Figure 1.

CEV subjects were given the DVD and a single instruction page highlighting which exercises to perform. For the PT group, a physical therapist gave subjects thirty minutes of in-person instructions and a handout outlining the exercises taught during the session. Both groups were then asked to return after one week of home practice. Four exercises were tested: scapular retraction, standing rows with elastic resistance, external rotation, and internal rotation with elastic resistance. All subjects were asked to record the number of days they practiced the exercises, and were required to perform at least three days of home practice. In addition, subjects at UNC were asked to score their resource’s “Ease of Use” and “Ease of Understanding” on a scale of one to 10 (with 10 being the best score), developed by the authors. Subjects at HM were not asked these questions as part of the study.

On the day of testing, subjects were video recorded from the front and side while they performed ten repetitions of each exercise without coaching. Blinded physical therapists then used the Shoulder Exercise Assessment Test (SEAT), a shoulder scoring criteria developed by an unaffiliated physical therapist and the author (DJB) to independently score subject performance on each exercise while blinded to group; this scale has yet to be validated for reproducibility between scorers (see Discussion). The criterion for SEAT scoring is displayed in Figure 2, with a higher score denoting more accurate performance. Scoring for each exercise was based on performance on the majority of the repetitions (i.e. correct performance in >6 repetitions was scored as accurate performance). Each subject was scored by two independent physical therapists at UNC and three independent physical therapists at HM. The average score for each subject (from two PTs at UNC and three at HM) was used in all statistical analyses. All statistical analyses were conducted using non-parametric statistical analysis (with significance at p < 0.05) using Prism 5. Statistical tests used are noted in the text.

RESULTS
Table 1 presents all outcomes for the total subject pool. All outcomes are reported as mean +/- standard error.
Subjects in the CEV group at UNC reported a strong trend towards increased Ease of Understanding for their material, although the result was not statistically significantly different than the PT group (9.31 ± 0.24 vs. 8.08 ± 0.57; p = 0.06, Mann-Whitney U test; 95% CI [-2.39, -0.07]). Subjects in the CEV group at UNC also reported a strong trend towards increased ease of use, though the result did not reach significance (9.44 ± 0.20 vs. 8.67 ± 0.40; p = 0.09, Mann-Whitney U test; 95% CI [-1.62, 0.08]). As noted in the Methods, subjects at HM were not asked about ease of use or understanding. Combining subjects from UNC and HM, there was no difference in the number of times in a week subjects in each group practiced their exercises (3.94 ± 0.34 vs. 3.83 ± 0.21 for CEV vs. PT visit).

Comparing the CEV and PT groups across the two institutions, the SEAT scores for each exercise was not significantly different from one another except for the standing row (Kruskal-Wallis test with post-hoc Dunn's test) (Figure 3). The subjects at HM received lower scores independent of participating in the CEV or PT group.

Combining the data from both institutions, no significant differences were found between the CEV and PT visit group for any of the four exercises: scapular retraction (3.87 ± 0.11 vs. 3.86 ± 0.12), standing row (2.99 ± 0.11 vs. 2.95 ± 0.13), external row (3.34 ± 0.12 vs. 3.24 ± 0.11), and internal row (3.49 ± 0.13 vs. 3.43 ± 0.12). These results are shown in Figure 4. Finally, a total SEAT score was calculated for each subject by adding the score for each individual exercise and dividing by the number of criteria scored. No significant difference was found between the CEV and PT visit group for the total score (0.80 ± 0.02 vs. 0.79 ± 0.02, (Figure 4).

**DISCUSSION**

Given the importance of effectively communicating patient instruction during physical therapy visits...
with increasingly limited patient-provider interaction time, the hypothesis of this study was that using a DVD instruction in general, and CEV instruction in particular, would be as effective as direct clinical instruction in delivering the critical information necessary for patients to accurately perform home shoulder exercises. To this end, this study was designed to examine if a corrected error video (CEV) would be as effective as a single visit with a physical therapist (PT) in teaching shoulder exercises when subjects were re-tested one week after initial instruction. Subjects were evaluated using a scoring system (SEAT) that was developed by the author (DBJ) and a physical therapist independent of those used in the study to score subjects. For four shoulder exercises (scapular retraction, standing row, external rotation, internal rotation) there was no difference in exercise performance for subjects taught by a CEV compared to those who had a formal PT visit and were given a take-home handout. Furthermore, subjects at UNC in the CEV group demonstrated strong trends in rating the tool significantly easier to understand and use. The results of this study build on previous work using instructional videos to teach PT exercises by using a CEV. This format demonstrates not only the correct method of performing an exercise, but also common incorrect methods and mistakes to avoid. These findings concur with previous studies demonstrating that CEV instruction was as effective as one-on-one provider-subject interaction in teaching PT exercises.1,9,10,11 These results are also in agreement with previous work using various motor tasks (for example, throwing with subject’s non-dominant hand) that have demonstrated the utility of corrective feedback in improving performance.13 Importantly, the current results extend on previous work using a CEV11 by demonstrating the efficacy of CEV using an independently created video and that information gained from the CEV can be retained by subjects up to one week later. Additionally, the reproducible effect at two separate institutions (UNC and HM), using distinctly different subject populations and DPTs, strengthens the conclusion that CEV is an effective method to communicate shoulder exercise

<table>
<thead>
<tr>
<th>Table 1. Descriptive outcomes for CEV and PT groups and PT group for all subjects (n = 58)</th>
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<tbody>
<tr>
<td><strong>Ease of Understanding</strong></td>
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<tr>
<td></td>
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<tr>
<td><strong>Ease of Use</strong></td>
</tr>
<tr>
<td><strong>Times Practiced per week</strong></td>
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<tr>
<td><strong>Scapular Retraction (SEAT A score)</strong></td>
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<tr>
<td><strong>External Rotation with Elastic Resistance (SEAT B score)</strong></td>
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<tr>
<td><strong>Internal Rotation with Elastic Resistance (SEAT C score)</strong></td>
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<tr>
<td><strong>Standing Row with Elastic Resistance (SEAT D score)</strong></td>
</tr>
<tr>
<td><strong>Total SEAT Score</strong></td>
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</tbody>
</table>

* = statistically significant difference between groups at p<0.05
instruction when compared to one-on-one therapist interaction, and is therefore a useful alternative method of teaching.

There are limitations to the current study. The SEAT scoring system used to grade subjects has not been thoroughly validated. Future studies will attempt to validate the system. Such a tool will prove useful in objectively evaluating proper execution of PT exercises. Another limitation of this study is our sole focus on shoulder exercises; it is plausible that exercises for other body parts may be harder or easier to teach using the CEV. Nevertheless, these results provide proof-of-principle that the use of a CEV is an effective tool. Subsequent work will extend this investigation to include other body parts (i.e. knee, ankle etc). A final limitation is that the patient population consisted of subjects without shoulder pathology. Future efforts will repeat this study in the injured patient population rather than in recruited subjects, evaluating differences in outcomes from injury (strength, range of motion etc) rather than just instructional efficacy.

Figure 3. Performance on Individual Exercises as well as the Total SEAT Score for CEV vs PT Visit group, separated by institution of recruitment.
CONCLUSIONS

In summary, this study demonstrates that the use of a CEV to teach shoulder exercises results in equivalent performance one week after instruction when compared to the use of in-person instruction. These results show that a CEV is a useful tool to assist physical therapists in communicating information to subjects.

REFERENCES


ABSTRACT

Background: Physiotherapists and other practitioners commonly prescribe foam rolling as an intervention, but the mechanistic effects of this intervention are not known.

Purpose: The aim of this investigation was to establish if a single bout of foam rolling affects flexibility, skeletal muscle contractility and reflected temperature.

Methods: Twelve adolescent male squash players were evaluated on two separate occasions (treatment and control visits) and were tested on both legs for flexibility of the hip flexors and quadriceps, muscle contractility (as measured by tensiomyography) and temperature of the quadriceps (assessed via thermography) at repeated time points pre- and post a 60s rolling intervention (pre-, immediately post, 5, 10, 15, and 30 minutes post). They rolled one leg on the treatment visit and did not perform rolling on the control visit.

Results: The main outcome measure was the flexibility of hip flexor and quadriceps at repeated time points up to 30 minutes post intervention. The average foam rolling force was 68% of subject's body weight. This force affected the combination of hip and quadriceps flexibility (p=0.03; 2.4 degrees total increase with foam rolling) but not each muscle independently (p = 0.05 – 0.98) following a single 60s bout. Muscle contractility is not affected (p = 0.09 – 0.93) and temperature is not increased by foam rolling across time points (p=0.19).

Conclusions: A single sixty-second bout of rolling applied to the quadriceps induces a small significant change in flexibility that is of little practical relevance, while muscle contractility and temperature remain unchanged. Investigation of larger doses of rolling is merited in athletic populations to justify current practice.

Level of Evidence: 2c

Keywords: Adolescent, flexibility, tensiomyography, thermography

Original Research

SIXTY SECONDS OF FOAM ROLLING DOES NOT AFFECT FUNCTIONAL FLEXIBILITY OR CHANGE MUSCLE TEMPERATURE IN ADOLESCENT ATHLETES

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INTRODUCTION
The use of self-myofascial release techniques to aid recovery using a foam roller is increasingly popular, particularly as it is one of the first steps used by a pro-active athlete in self-management of complaints. The practice of foam rolling appears to have outpaced the scientific literature with limited publications available on its use. Rolling is believed to have similar effects to massage, which include relief of muscle tension, increased flexibility, and improved range of motion (ROM). There are claims that foam rolling can increase blood flow and joint ROM although such claims are mostly inferred from research that has been performed on massage. Currently there are no specific recommendations regarding the duration of foam rolling. While studies have been performed, none have examined the dose response of differing bouts to investigate the relationship between frequency and or volume with outcome. All studies to date have used multiple bouts either within or across muscles without justification. Only one study to date has examined the pressure exerted on the foam roller during the activity and a separate study has examined the force that is exerted through the roller. The differing forces through the roller and subsequently delivered to muscle vary based on individual's technique and body mass, and may influence the outcome from foam rolling.

Several authors have shown that ROM is improved by foam rolling. Each of these studies assess the effects of foam rolling after exercise. There have been no considerations of foam rolling from a starting point of no exercise in order to elucidate the mechanism for any action it may have. It has been proposed that thixotropy, where heat or pressure is applied to a material in order to make it less dense and more fluid, may contribute to the effectiveness of foam rolling.

If thixotropy is an important mechanism of action, the ability to quantify a temperature change that an intervention induces would appear to be essential. Foam rolling induced changes in ROM have been suggested to be associated with changes in temperature. The use of a non-contact diagnostic tool such as thermography allows for quantification of any temperature changes induced by foam rolling that have not previously been described.

Any temperature changes may in turn affect the muscle's contractile properties such as contraction time and force production. Tensiomyography (TMG) can evaluate the involuntary contractility of the muscle and is influenced by the viscoelastic properties of the muscle. TMG has commonly been used to assess the muscle damage caused by an intervention but has also been used to monitor muscle alterations that occur following bed rest and to assess any effects of recovery strategies. TMG as a technique measures the maximal radial displacement of the muscle belly via a digital transducer, when a contraction is generated by an external electrical stimulus. It offers information about different parameters relating to the magnitude and speed of muscle contraction and the mechanical properties of skeletal muscle. TMG can non-invasively quantify muscle function through measurement of muscle stiffness, time and speed of contraction and any subsequent changes in these variables from an intervention.

The goal of any foam rolling or myofascial release is to influence flexibility and/or ROM. Flexibility has been widely researched using a range of different methods and devices. Some utilized active participants, others passive. Few have utilized a standardized force during application in order to ensure that the measurement of flexibility is not simply a measure of a patient's tolerance to a stretch. This ensures reliable technique with an objective end point. Foam rolling is commonly prescribed by physiotherapists and applied strength and conditioning practitioners but the mechanistic effects of this intervention are not known. The aim of this investigation was to establish if a single bout of foam rolling affects flexibility, skeletal muscle contractility and reflected temperature. The hypothesis was that flexibility would increase due to foam rolling with concurrent reduction in contractility of the muscle and increases in temperature. The null hypothesis was that there would be no effect of foam rolling on the measures of flexibility, muscle contraction or muscle temperature.

METHODS
Subjects
A prospective cohort of male adolescent squash players from an elite sports school (n = 12, 55.0 ± 13.4...
kg, 160.7 ± 13.5 cm, 67.7 ± 32.6 Σ8 skinfolds mm, -0.08 ± 1.7 yrs from Peak Height Velocity, 14.2 ± 1.4 yrs) was utilized. Testing was conducted on two separate occasions separated by 7-12 days. In each case testing took place following a standardized rest day. The treatment leg and order was determined by an online randomization tool (sealedenvelope.com), which was then matched to the 12 subjects by drawing from a hat. The study was approved by both the local research and University ethics committees and conformed to the recommendations of the Declaration of Helsinki.

Protocol
On one occasion (treatment) the subject performed the rolling intervention on the anterior part of the thigh of one leg while the contralateral limb acted as a control and on the other occasion (control) the subject lay in a prone position for the same duration but with no foam rolling to act as a full control. On both occasions the intervention occurred at the start of the athlete group’s morning training session (10 – 12h) before any exercise had been undertaken and following a rest day. Athletes were free from injury, and were excluded from testing if they were not able to complete in all aspects of training.

Using the low and flat section of a commercially available foam roller (Figure 1A; The Grid, Trigger Point, Texas, USA) the subjects performed rolling on the anterior thigh of the treated leg. They placed their body weight on the foam roller, which was placed on a force plate (400 Series Force Plate, Fitness Technology, Adelaide, Australia) sampling at 600 Hz. This measured the actual force applied through the roller throughout the intervention. Other than the leg on the roller (or force plate in the control condition) the subjects had two points of contact with the floor, both forearms placed in front of the force plate (Figure 1B). The non-rolling leg was elevated and fixed in a plank position via activation of posterior chain musculature. The rolling leg did not contact the floor. The body was held in a straight line with the trunk stable and the subject facing the floor. The subjects started at the proximal aspect of the thigh and rolled down toward the knee in one fluid motion. Upon reaching the required depth, the direction was reversed. The speed was controlled by a metronome (2s per pass) and the depth was visually indicated by tape on the force plate corresponding to the length of the subject's thigh. The rolling intervention covered the full anterior thigh musculature from just below the anterior-superior iliac spine to just superior to the patella. The duration of the rolling intervention was 60s reflecting the minimum dose prescribed by physiotherapy professionals working with the athletes, meaning that 30 full rolls were completed (15 in each direction).

Prior to undertaking any foam rolling the subjects were asked to stand with their feet aligned to markers on the floor, to ensure a consistent position (feet shoulder width apart), in front of a rubber mat, to minimize reflected heat from the environment, for a thermal image to be taken to assess the baseline condition of reflected temperature. Subjects were then assessed for flexibility (passive ROM) of the quadriceps and hip flexors using the ‘angle at force standardized endpoint’ technique.30 Subjects then underwent Tensiomyography assessment (TMG) to examine the state of the muscle. These measures were repeated at 0, 5, 10, 15 and 30 minutes post intervention to examine any acute effects of the foam rolling intervention, subjects lay in a supine position between measures. The measures were taken from both left
and right limbs to allow each subject to serve as their own internal control.

**Procedures**

**Flexibility**
The primary outcome measure was that of hip flexor and quadriceps flexibility. The method used to assess flexibility replicated the method described by Fourchet and colleagues of the ‘angle at force standardized endpoint’, a video based method for flexibility assessment that has been established to have moderate-to-good reliability when used to monitor the passive ROM of adolescent athletes. The same investigator consistently manipulated the patient and analyzed the video for the angle, to minimize test-retest variance. The camera obtaining the image was always perpendicular to the end of the plinth and at a distance of 3m with the same zoom setting. A hand-held dynamometer (Compact force gauge, Mecmesin, Slinfold, United Kingdom) with a digital scale (0.01-N increments) was used to apply the standardized force. The flexibility assessments were performed with the athlete supine. For the hip flexor measurement the pelvis was aligned at the end of the plinth. Following marking of identifiable anatomic landmarks with a dermatological pen for easy identification on the video, the operator maintained the non-tested limb in a maximally flexed position towards the abdomen, and allowed the lower limb to be tested to hang off the end of the plinth in neutral rotation. The tested limb was further extended with a force of 98.1N. The hip flexor measure was the angle formed between the body and the extended lower limb, as measured from a digital image. For the quadriceps measure the patient’s position was adjusted so the mid-thigh was aligned with the end of the plinth. The uninvolved limb was maintained in a maximally flexed position towards the abdomen and the lower limb to be tested was in neutral position. The dynamometer was used to passively flex the tested knee with a force of 78.5N. The quadriceps measure was the knee flexion angle, as measured from a digital image. The measurements were then repeated on the contralateral side. Regardless of the treatment side the subjects left leg was assessed first at each time point. Using the digital images obtained during the tests, digital motion analysis software (Dartfish, Classroom v.5.5, 2009, GEAR Software B.V., Helmond) was employed to measure the angles of interest. This occurred in a blinded fashion with the angles only matched to the trials after all analysis was complete. The final angles for each muscle group were measured to the nearest 0.1° according to the marked anatomic landmarks. Overall flexibility of the leg was taken as the combined flexibility (sum) of the hip flexor and the quadriceps angles for each limb.

**Tensiomyography**
For a non-invasive measure of muscle contractility, TMG was employed. This technique creates radial displacement of the muscle belly in response to an electrical stimulus (~100mA) conducted through the underlying muscle tissue. These displacements are recorded at the surface of the skin using a spring loaded displacement sensor (TMG-BMC Ltd, Ljubljana, Slovenia). The sensor was consistently retracted to 50% of its length to ensure a consistent initial pressure. The sensor was positioned perpendicular to the thickest part of the rectus femoris muscle belly. This position was established with visual inspection of the voluntary contracted rectus femoris and palpation of the area. Self-adhesive electrodes were placed ~5cm on opposite sides of the sensor in the sagittal plane, over the rectus femoris. Once the exact position of the sensors was determined they were marked with a dermatological pen to ensure placement remained constant throughout the visit. Before proceeding an acetate layer was used to mark the sensor and electrode positions over the skin on each leg. This traced the placement as well as any anatomical or visual landmarks for each subject to ensure consistent placement on the second visit.

All measurements were performed with subjects in a supine position on a padded plinth. A triangular foam wedge was placed under the knee to create a knee joint fixed at 120° angle. A series of contractions of increasing amplitude (~10mA) was used to obtain a maximal response i.e. no further muscle displacement could be produced as evidenced by a plateau in the twitch response curves. Only the maximal output data were used for analysis. Maximal radial muscle belly displacement (Dm), contraction time between 10 and 90% Dm (Tc) and
the time taken from onset of the electrical stimulus to 10% of the maximal radial displacement (delay time; Td) of the rectus femoris were measured via TMG at each time point. These collective measures provide a comprehensive analysis of muscle state with each representing a different facet of contractility. Dm (expressed in millimeters) depends on the muscle tone or stiffness. High scores indicate a lack of muscle tone (i.e. more compliant and relaxed muscle – expected after rolling). The time variables (measured in ms) represent the reaction time of the muscle (Td) and the subsequent time to contract (Tc). Associating the changes in Dm, Tc and Td can give insight into changes caused by foam rolling (i.e. a decrease in Dm with increase in Tc and Td would suggest fatigue).

Thermal Imaging
Thermography is a non-invasive technique used to measure specific thermal responses at a superficial level. The technique has previously been used to help quantify objective measures that have previously required subjective feedback such as the effects of massage. Following palpation of the area for TMG placement a 50 x 50 mm area was marked around the area where the electrode was to be placed, this was marked by four strips (3 x 50 mm) of inert aluminum tape (3M, Minnesota, United States) to allow measurement of a consistent region of interest from the thermal images. In post processing a consistent marker was placed in the software to allow assessment of the majority of the quadriceps. From the sample this size was 110 x 46 pixels. This size was chosen as it covered the majority of the subject’s anterior thigh without being too large (i.e. it exceeded the musculature and captured the background within the area).

An infrared camera (FLIR T600, FLIR Systems, Oregon, USA) was positioned on a level tripod directly in front of the area where the subject was to be photographed at a distance of 2 m. The height of the tripod was consistent across all subjects and allowed a clear image of the lower half of the body to be taken. The camera was allowed to stabilize in the environment 60 minutes before the first picture was taken. A constant skin emissivity was set to 0.98 in accordance with previous research. Prior to images being taken the camera was calibrated for the reflected heat and ambient conditions using the protocol recommended by the manufacturer. Images were taken pre the intervention, immediately post (0 minutes) and at all subsequent time points (5, 10, 15 and 30 minutes) with a consistent position of the subject and camera.

Statistical Analysis
Data are presented as mean ± SD. A 0.05 level of confidence was selected throughout the study. Statistical analyses were conducted using Minitab 17 (Minitab, Pennsylvania, United States). The normality of each measure was established. Each measure in turn was assessed as the independent variable against the time, condition and the interaction. A general linear model for repeated measures was used to assess normalized differences between conditions standardized to the Pre-condition and the force applied for each visit with factors of Time, Condition and their interaction for each variable. Post-hoc analysis was undertaken using Tukey’s HSD. The difference between the treated leg and the control leg were normalized for each time point to the initial Pre-measurement for each variable in each condition. Then the difference between the treatment condition and control condition were calculated and assessed after interactions between time and group were also examined.

In addition, probabilistic magnitude-based inferences about the true value of outcomes were employed for variables with a practical relevance. Dependent variables were analyzed to determine the effect of the designated intervention as the difference in change following each condition. To calculate the possibility of benefit, the smallest worthwhile effect for each dependent variable was the smallest standardized change in the mean – 0.2 times the between-subject SD for baseline values of all participants. This method allows practical inferences to be drawn using the approach identified by Batterham and Hopkins.

Inter- and intratrial reliability analyses were conducted on all dependent variables. All data used for reliability analyses were obtained from the control limb. Intertrial reliability was established using data obtained over the course of each individual trial.
Intrasession reliability was established via analyzing data from the same time points across control and treatment trials. Reliability was determined using intra-class correlation coefficients (ICC), calculated using the two-way random method, Pearson’s correlation coefficients ($r$) and coefficients of variation (CV) as previously described.\textsuperscript{38}

**RESULTS**

**Flexibility**

While there were differences between subjects for flexibility of hip flexor ($p=0.01$) and overall flexibility of the leg (combined flexibility of hip flexor and quadriceps) ($p=0.01$), there was no effect on quadriceps ($p=0.37$). There was no effect on hip-flexor, quadriceps or overall flexibility over time ($p=0.20$, $0.74$ & $0.34$ respectively). For condition there was no difference on hip-flexor ($p=0.62$) or quadriceps ($p=0.05$) flexibility (individually) though there was for overall change in flexibility where the control condition was 2.4 degrees lower overall than the treatment ($p=0.03$). There were no significant interactions for hip-flexor, quadriceps or overall flexibility ($p=0.21$, $0.98$ & $0.31$). The individual values are plotted in Figure 2 along with the mean values. The raw mean values are shown by treatment and condition in Table 1.

**Magnitude based inferences**

There were differences practically at 15 and 30 minutes using the inferential approach. In terms of flexibility there was a small effect in overall flexibility of the hip flexor and quadriceps combined that was possibly trivial mechanistically at 15 minutes post. At 30 minutes this difference was no longer present. While there were small changes in the hip-flexor and quadriceps data at 15 minutes the practical conclusion is that there are not enough data to be certain of this effect.

**TMG**

There was no effect on $T_c$, $D_m$ or $T_d$ of time ($p=0.99$, $0.49$ & $0.76$ respectively), condition ($p=0.10$, $0.24$ & $0.64$), nor were there any time*condition interactions ($p=0.52$, $0.98$ & $0.18$). The individual values are plotted in Figure 2 along with the mean values. The raw mean values are shown by treatment and condition in Table 1.

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**Figure 2.** Individual value plot of standardized differences to Pre condition based on condition (treatment or control). Mean values are marked.
Magnitude based inferences

There were some differences practically at 15 and 30 minutes using the inferential approach. In terms of Tc there was a moderate effect that is possibly negative at 15 minutes (i.e. the rolling condition increases the contraction time (slower activation)) at 15 minutes post. At 30 minutes this difference was small but positive rather than negative (i.e. the rolling condition demonstrated a decrease in the contraction time in comparison to the control). At 30 minutes there was a moderate increase in the delay time in the treatment condition that is likely negative (i.e. rolling causes the muscle to activate more slowly).

Thermography

Small area (23 x 20 pixels)

As presented in Figure 3 it is evident that there were no differences in temperature across each time point (p = 0.16). There were differences between conditions with the control condition being colder by 0.17°C (p < 0.01), although no time x condition interaction was present (p = 0.59).

Large area (110 x 46 pixels)

When analyses were performed on the entire quadriceps region a condition interaction was observed (p = 0.001) with the limb being colder in control condition (0.15°C), although no time x condition interaction was present (p = 0.08). The raw mean values are shown by treatment and condition in Table 1.

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<th>Condition</th>
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Tc = contraction time between 10 and 90% Dm, Td = the time taken from onset of the electrical stimulus to 10% of Dm, Dm = Maximal radial muscle belly displacement, HF = Hip Flexors

Table 1. Thermography, tensiomyography, and flexibility raw values by treatment leg and condition (presented as Mean ± SD).
directed through the foam roller into the force plate on average. The difference between the treatment and control conditions mean force exerted was significant (p < 0.01). Force exerted on the force plate (and roller) was similar between subjects across conditions (p = 0.21). The treatment condition ranged from a force of 27% body mass to 67% and an absolute force of 15.8 to 40.6 kg. The correlation between the relative and absolute values for the treatment condition was r = 0.69. The correlation between mass and average force in the treatment condition was r = 0.61.

Reliability
The reliability of the flexibility assessment employed here has previously been assessed and analyses indicated the measure has good reliability. Inter- and intratrial observations for TMG and thermography were all significantly correlated (all p < 0.05). Inter- and intratrial reliability statistics for TMG and thermography are presented in Table 2 along with the smallest worthwhile change that may be useful for future studies.

DISCUSSION
The aim of this investigation was to establish if a single bout of foam rolling affects flexibility, muscle contractility and temperature. The primary finding of this study was that foam rolling had no statistically significant effect on muscle contractility markers or temperature. While the overall flexibility was statistically greater in the treatment condition in practical terms this is insignificant as it is within the published coefficient of variation for the test (10.6%) or in this case 12.48°. The present study controlled for force applied to the limb as has been done previously, making the end point of range of motion measurement objective, rather than subjective. This may be one reason why no change in ROM was seen.

Previous authors have suggested that the mechanism that foam rolling utilizes to have an effect is similar to massage although no definitive consensus regarding the exact mechanism exists. A recent review has highlighted that while the performance effects of massage are limited (Hedges g = 0.19), massage can be effective if the recovery interval is short especially in untrained subjects. The current study attempted to examine a possible mechanism of foam rolling by monitoring temperature change and while objectifying the flexibility measure in order to attempt to gain greater insight into the
induced muscular changes that occurred, as measured by TMG.

The current data indicate there is a small but significant change after the intervention of 1 x 60 s bout of rolling. However, this may have little practical relevance for intervention. Other authors have used different repeated interventions (e.g. 3 x 60 s) without justification however, this may indicate that multiple bouts of foam rolling have a greater influence of the musculature due to a larger overall dose. Previous authors that examined flexibility measures, did not specify any pressure advice nor standardization for the participants and did not demonstrate a change in flexibility.41,42 Others that have used greater forces have shown greater increases in flexibility in what seems to be a dose response relationship. Sullivan and colleagues utilized a limited force of 13kg and found an increase in hamstring ROM of 4.3% and when using a higher force (25% of body mass; ~20 kg), Bradbury-Squires and colleagues demonstrated increases in knee-joint ROM by 10-16%.13,43 There has been no direct comparison of different pressures, however, in the present study an average of 50% of body mass (27.2 kg) was directed through the roller at the quadriceps. The authors of the current study did observe a range of forces being applied across subjects that differed in absolute terms. This is a potential source of variance – as is the change in load that is observed as the roller moves longitudinally across the muscle.39

This study utilized trained athletic subjects. Only one other study has investigated the effects of foam rolling utilizing athletes as the subject group.44 Previous comparisons of the chronic effects of static stretching in trained and un-trained subjects have reported greater effects in untrained individuals45 and this may therefore be a factor that could explain the lack of results reported both in this study and that of Mikesky and colleagues as trained athletes may already possess a greater ROM due to regular exercise and stretching and therefore if the flexibility is not compromised foam rolling would not induce an increase in ROM.

A criticism of the mechanistic approach of the current study may be drawn from the massage literature as this suggests that effects occur at the systemic whole-body level and as such designs that

| Table 2. Inter and intra trial reliability of Tensiomyography and Thermography measures. |
|-----------------------------------------------|---------------|---------------|---------------|---------------|---------------|---------------|
| ICC r CV (%) SWC |
| Inter trial | Intra trial | Inter trial | Intra trial | Inter trial | Intra trial |
| Tensioomyography |
| Tc | 0.82 | 0.65 | 0.82 | 0.79 | 7.5 | 7.6 | 0.86 (ms) |
| Td | 0.92 | 0.91 | 0.91 | 0.80 | 3.8 | 3.6 | 0.68 (ms) |
| Dm | 0.88 | 0.86 | 0.88 | 0.80 | 17.5 | 13.1 | 0.56 (mm) |
| Thermography |
| 100 x 46 | 0.92 | 0.91 | 0.92 | 0.78 | 0.8 | 1.1 | 0.23 (°C) |
| 23 x 20 | 0.91 | 0.88 | 0.91 | 0.82 | 1.0 | 1.4 | 0.26 (°C) |

ICC = intra-class correlation coefficient, CV = coefficient of variation, SWC = smallest worthwhile change, r = Pearson’s correlation coefficient, Tc = contraction time between 10 and 90% Dm, Td = the time taken from onset of the electrical stimulus to 10% of Dm, Dm = Maximal radial muscle belly displacement
massage only one limb and use the contralateral as an internal control should be avoided.\textsuperscript{46} The counter argument is that with the current research design the authors utilized a full control condition in order to detect the true difference of any intervention. The dependent variables in this research were more local than systemic in nature.

Previous literature has looked at foam rolling as an acute recovery intervention after inducing muscle damage.\textsuperscript{2,10,47} In the current study an intervention was examined without a preceding bout of muscle damage. The reason for this was to try and separate the size of any effect of foam rolling itself on flexibility rather than as an analgesic or increasing the compliance of injured muscle. While it is beyond the scope of this investigation to comment at length, the eccentric muscle damage induced in previous studies is not always like that encountered in athletes in training in terms of scope or mechanism. Also the acute use of foam rolling immediately post session is not as commonplace as its use as part of the warm up before the next session 24 or 48 hours later.\textsuperscript{48}

While four studies have examined the time course of flexibility changes following myofascial release most are limited to 10 minutes post treatment.\textsuperscript{1,7,47,49} Halperin and colleagues showed increased ROM at one and 10 minutes post intervention. MacDonald and colleagues reported increased ROM at two and 10 minutes post-intervention. One study looked at longer time periods and found no effect at 30 and 60 minutes post intervention, there was however an effect after 10 minutes, however the authors did not specify the duration of rolling on the hamstrings.\textsuperscript{47} Only one study has observed no effect on flexibility at 10 minutes similar to this study. The study in question tested the plantar flexors and used a rolling protocol of 3 x 30s.\textsuperscript{49}

**Future directions**

Future study in the area may utilize a larger relative dose (likely through a series of repeated reps) to see if this induces an effect. This dose-response relationship remains to be elucidated in order to scientifically influence practitioner’s prescriptions.

While the dose response relationship of volume on flexibility is unclear, it appears that there is a greater effect with a greater force and most studies have found meaningful improvements with around 1-2 minutes of treatment.\textsuperscript{4} While the load applied during rolling was measured, an approach could be taken to use the foam roller at a standardized load on the muscle relative to the subjects body weight, though this approach would likely see the subject be in a supine, passive position as the force is imposed on them rather than self-applied. As such this may not have as high a practical relevance. The dose response relationship seems clearer for force but again is an area for future investigation.

Additionally, measures of discomfort may need to be recorded during the rolling intervention as there may be a psychological effect for adolescent athletes who may experience discomfort during the intervention. Also, potentially without the discomfort being of a sufficient level they may not perceive it to have a benefit.\textsuperscript{50,51} Any future investigation should utilize a standardized end point for testing flexibility or ROM that is objective rather than subjective.

The time course of the intervention was only followed up to 30 minutes post. Investigation of up to one hour post may be merited as athletes utilize foam rolling within their warm ups which can occur in excess of one hour prior to competition.\textsuperscript{52,53}

**CONCLUSION**

Foam rolling had no practically significant effect on flexibility and no effect on muscle contractility markers or reflected temperature within 30 minutes of rolling. The present study controlled for force applied to the limb and observed no change in ROM.

**REFERENCES**


27. Folpp H, Deall S, Harvey L a, Gwinn T. Can apparent increases in muscle extensibility with regular stretch be explained by changes in tolerance to stretch? *Aust J Physiother.* 2006;52:45-50.


ABSTRACT

Background and Purpose: The patella plays an important role in knee biomechanics and provides anterior coverage of the knee joint. One to two percent of the population has an anatomical variant of patella called a bipartite patella that usually does not cause pain. However, occasionally after injury or overuse during sport it can be a source of anterior knee pain. The purpose of this case report was to present a rare variant of bipartite patella and highlight conservative treatment of this condition.

Study Design: Case Report

Case Description: A 35-year-old female patient presented with persistent bilateral non-traumatic anterior knee pain of a six-year duration that was enhanced by strenuous kinds of sport activity. Standard radiographs and MRI revealed the presence of bipartite patella with medial pole cartilage edema bilaterally. Conservative care including physical therapy, extracorporeal shock wave therapy (ESWT), and viscosupplementation was utilized.

Outcome: After treatment VAS decreased to 0/10 from 5/10 in the left knee and 1/10 from 5/10 in the right knee. The Kujala Scores improved after treatment to 100 and 95 for the left and right knees respectively. The subject returned to full sport activity and work as a fitness instructor without pain and limitations.

Discussion: This case describes a rare finding of bilateral medial bipartite patella and the successful use of physical therapy with viscosupplementation in patellar pain caused by bipartite patella. It also supports the use of Extra Corporeal Shock Wave Therapy in bipartite patella pain as a supplement for therapy.

Level of Evidence: 4

Keywords: Anterior knee pain, bipartite patella, Magnetic resonance imaging

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INTRODUCTION
The patella is the largest sesamoid bone in human body, positioned longitudinally in the quadriceps muscle fascia, between the quadriceps and patellar tendons. It plays an important role in knee biomechanics and provides anterior coverage of the knee joint. The prevalence of anterior knee pain in the female athletic and recreational athletic population reported in the literature is 12-13%. Usually the patella begins to ossify at the age of three from a single ossification center. In some cases, however, there are two or more ossification centers that can form the patella. Overuse and repetitive trauma of this region may lead to excessive strain at the site of incomplete fusion causing pain and discomfort. The ossification centers generally fuse within the body of the patella in adolescence but sometimes this fusion is incomplete, resulting in a divided patella, known as a bipartite patella. Bipartite patella is considered a normal variant of the patella and is present in 1-2% of the population. The majority of people having bipartite patella are unaware of the condition. Overgrowth of the supero-lateral quadrant of the patella is frequently observed but often is considered an incidental finding during differential diagnosis of knee injuries or disorders. Although the bipartite patella may be the only anatomical abnormality in painful knee, it may not be the source of pain. The exact frequency of painful bipartite patellae is unknown since only case reports or case series were available in the published literature.

Saupe classified bipartite patella into three types according to anatomical variations depending on the localization of the unfused fragment of patella (Figure 1). In Type I, present in 5% of people with anatomical abnormalities of the patella, the fragment is localized in the inferior pole. A more common variation present in 20% is Type II, where the fragment is localized at the lateral margin, while in 75% of the cases the bony fragment is localized at the supero-lateral portion of patella, and is described by Saupe as Type III. This classification system does not describe a medial position of an unfused bony fragment of the patella. The authors found only one report of medial bipartite patella published 1978. According to the literature regarding failed conservative treatment (when the pain is not relieved over several months) of bipartite patella, surgical intervention should be considered. Several surgical methods for the treatment of the most common supero-lateral bipartite patella have been described. The most commonly used are: vastus lateralis release, lateral retinacular release technique or excision of the painful accessory fragment, and all these methods can be done either by open procedure or using arthroscopic technique. Halpern and Hewitt achieved pain relief in a case of medial bipartite patella after excision of additional fragment.

Due to lack of sufficient description regarding this anatomic variation, the purpose of this case report was to present a rare variant of bipartite patella and highlight conservative treatment of this condition. The subject was informed that the data concerning the case would be submitted for publication.

SUBJECT PRESENTATION
A 35-year-old female a fitness instructor presented with persistent bilateral anterior knee pain for the
previous six years without history of trauma. She reported an inability to perform strenuous kinds of sport activity like running and jumping. The pain also intensified during squats. There was a history of similar pain in the left knee at the age of 13. Diagnostic arthroscopy was performed at that time with all negative findings. Unfortunately, no radiographs were ordered at the time of surgery, and all diagnostic effort was focused on soft tissue structures like cartilage or meniscal lesions. After that arthroscopy she did not complain of knee pain for many years, until six years prior she began to experience pain a few times per year only after substantial effort. Over time the pain intensified and during the previous year the subject experienced pain during walking, climbing stairs, and at rest. After extensive activities performed for her work such as squats, jumping, and cycling, the subject would complain of swelling of both knees and the sensation of crepitus beneath both patellae. The subject was treated non-operatively for five years in another center mainly by nonsteroidal anti-inflammatory drugs (NSAID’s) and glucosamine and chondroitin sulfate supplementation. Some physical therapy had been attempted, but the pain relief was partial and pain quickly returned.

**EXAMINATION**

Physical examination revealed tenderness over the supero-medial patellar pole on both knees. Based on negative tests including the Lachman, pivot shift, anterior and posterior drawer, Appley, McMurray, and varus/valgus stress tests meniscal and ligaments injuries were ruled out. A visible deformity and thickening over the supero-medial patellar pole was present the bilaterally. This was the most painful area of the knee. The subject scored 67 (on both the right and left knees) on the Kujala Scoring Questionnaire for patient reported outcomes related to patellofemoral dysfunction. (Table 1) This scoring system is designed to evaluate subjective symptoms and functional limitations in patients with patellofemoral pain and dysfunction. Minimum score is 0 and maximum is 100, the higher the score the better the function of the knee.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Right</th>
<th>Left</th>
<th>Maximum Score possible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limp while walking</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Support</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Walking</td>
<td>3</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Using stairs</td>
<td>8</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Squatting</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Running</td>
<td>8</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Jumping</td>
<td>2</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Prolonged sitting</td>
<td>8</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Knee pain</td>
<td>6</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Knee swelling</td>
<td>6</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Subluxations</td>
<td>6</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Tight muscle atrophy</td>
<td>3</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Flexion deficiency</td>
<td>3</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total Score</strong></td>
<td><strong>67</strong></td>
<td><strong>67</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Standard radiographic examination (Anterior-posterior and skyline views) revealed a bipartite patella at the supero-medial pole of the patella in both knees (Figure 2). The accessory fragments were both irregular in shape. A larger fragment (2 cm width) was found in left knee compared with 1 cm width fragment present in the right knee. The Insal-Salvati index, the ratio of the patella tendon length (TL) to
the length of the patella (PL), was 1.1 for the right knee and 1.0 for the left.

Further imaging techniques were scheduled to assess soft tissue structures, especially the articular cartilage and retinacula around the knee joints. Bilateral MRI examination confirmed the presence and the sizes of the accessory patellar bony fragments (Figure 3). The gaps between bony fragments and the bodies of the patella were filled by dense fibrous, heterogeneous tissue. Of note, the medial retinaculae were thickened at both accessory fragment attachments. The hyaline cartilage beneath the medial poles of the patellae appeared heterogeneous with increased width, however, with continuity intact. The cartilage in the remaining parts of the patellar surfaces of the patellofemoral joints was thinned with notable fissuring and cracking, and subchondral bone edema noted. No other abnormalities of soft tissue structures around the patellae and knee were reported.

**INTERVENTIONS**

The treatment plan was comprised of rest, limitation of sports activities, and also ultrasound therapy, accompanied by cryotherapy. Physical therapy interventions included stretching and strengthening exercises for hamstring and quadriceps muscles started immediately to ensure optimal length and strength of those muscles, supplemented by massage and soft tissue therapy for the quads, hamstrings and ilio-tibial bands, along with mobilization of the patella. The purpose was to regain full range of motion with proper patella tracking. Low intensity ultrasound and cryotherapy were utilized in the region of the additional patellar fragment and gap in order to reduce swelling and pain.

The patient was instructed in exercises for the gluteal, abductor and quadriceps muscles as well as stretching and deep tissue massage of gluteal, quadriceps, hamstring muscles and iliotibial band using a foam roller. At week four functional training, CORE stability interventions, and correction of faulty movement patterns during exercise were added. (Table 2) After eight weeks of rehabilitation and only partial improvement surgical excision of the acces-
<table>
<thead>
<tr>
<th>Week of rehabilitation</th>
<th>Rehab program</th>
<th>Exercise/Physiotherapy</th>
<th>Purpose</th>
<th>Repetition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-12</td>
<td>Hip strengthening</td>
<td>Hip Abduction</td>
<td>Decreasing level of pain and swelling.</td>
<td>3x8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hip Adduction</td>
<td></td>
<td>3x8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hip Extension</td>
<td></td>
<td>3x8</td>
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<tr>
<td></td>
<td></td>
<td>Hip IR/ER</td>
<td></td>
<td>3x8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unilateral supine bridge</td>
<td></td>
<td>3x8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Side bridge (60 sec. or till maintaining proper position)</td>
<td></td>
<td>3x8</td>
</tr>
<tr>
<td>1-12</td>
<td>Flexibility</td>
<td>Individual practice with rehabilitant, mobilization, hip rotators, quadriceps and hamstring</td>
<td>Regaining full non painful range of motion in the knee</td>
<td>10-30 min/day Hamstring held for 30-60 sec with 30 sec relaxation,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>stretching</td>
<td></td>
<td>3x8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>quadraticips and rotators stretch held for 30 sec.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-12</td>
<td>Quadriceps strengthening</td>
<td>Sitting isokinetic contractions</td>
<td>To increase strength of knee extension and vastus medialis strengthening.</td>
<td>3x10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ball squats- with ball behind the back</td>
<td></td>
<td>3x10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Step ups</td>
<td></td>
<td>3x8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Step downs</td>
<td></td>
<td>3x8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Single leg ¼ squat</td>
<td></td>
<td>3x8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Foam roller extensions (no weight)</td>
<td></td>
<td>3x10</td>
</tr>
<tr>
<td>8-12</td>
<td>Functional training</td>
<td>Side to side lunge</td>
<td>To strengthen femoral and hip muscles as well to gain stability</td>
<td>3x8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lateral duck under squats</td>
<td></td>
<td>3x8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>½ squat, ½ deadlift</td>
<td></td>
<td>3x8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Step up/downs</td>
<td></td>
<td>3x5</td>
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<tr>
<td></td>
<td></td>
<td>Rotational step up</td>
<td></td>
<td>3x5</td>
</tr>
<tr>
<td></td>
<td>CORE exercises</td>
<td>Bridge</td>
<td>Strengthen hip abductors</td>
<td>3x10</td>
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<tr>
<td></td>
<td></td>
<td>Clamshell exercises with Resistance Band</td>
<td></td>
<td>3x10</td>
</tr>
<tr>
<td></td>
<td>Bad movement patterns</td>
<td>One leg deadlift</td>
<td>Correct bad movement during exercises</td>
<td>3x8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Supported squat</td>
<td></td>
<td>3x10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bear squat (bear exercise position and squatting backward)</td>
<td></td>
<td>3x10</td>
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</tbody>
</table>
A sensory fragment was advised by the physician. The patient refused operative intervention. Therefore, the previous conservative interventions were followed with viscosupplementation injections performed by the physician (SynVisc, HyalganGF-20) on both knees (injections in each knee joint once a week for three weeks) in order to reduce friction, and the use of NSAID drugs to relieve pain. Subsequently, extracorporeal shock wave therapy (ESWT Rosetta System, CR Technology) was initiated on both knees during further strengthening exercises.10,11 Shock wave therapy was applied directly to the source of pain in the region of the bipartite patellae. On MRI there was bone edema noted, which is related to an increase in interstitial fluid and believed to be a source of pain. ESWT is believed to act physiologically on the tissue by inducing an acute inflammatory reaction, as well as increasing blood flow and oxygen supply. It also is suggested to enhance tissue healing and has some analgesic effect. Recent evidence suggests that ESWT therapy shows significantly better clinical results in decreasing pain caused by bone marrow edema than drug interventions.11 In this case report ESWT was used to reduce bone edema and the pain caused by it. The interval between shock wave treatments was five days. At first patient reported a mild pain increase to VAS 7/10 after ESWT procedure from the initial VAS pain scores of 5/10 in both knees. The ESWT therapy consisted of five sessions delivered using medium energy of 0.55mJ/mm² of about 1000 impulses each treatment session.10,11 After three weeks of ESWT, the subject showed dramatic improvement, and the VAS decreased to 0/10 in the left knee and 1/10 in the right knee. The Kujala Score in the left knee after treatment improved to 100 and in the right knee 95. After improvement patient was tested with single leg squat, leg crossover hop, vertical jump and four hop double leg jump with no pain and discomfort during exercises. (Table 3) Full painless range of motion was achieved in both knees. Patient returned to her sport activity with no pain during squats, cycling and jumping.

**DISCUSSION**

For most anterior knee pain syndromes, the exact cause of pain remains unknown. Therefore, most agree that conservative interventions should be the first choice of treatment. In cases of bipartite patellae the proposed source of pain is the gap between bony fragments. Oohashi et al12 examined the interposed tissue harvested from the gap between the fragment and the body of the patella during surgery and found many histological tissue types: fibrous and fibrocartilage tissue, as well as hyaline cartilage. In the interposed tissue, pathological abnormalities were also observed like diffuse degeneration and necrosis, focal necrosis of the fibrocartilage and trabecular bone, and lack of blood vessels. The bone marrow adjacent to the interposed tissue, however, showed multiple blood vessels, and trabecular bone surfaces were filled with numerous osteoclasts.12 This avascular tissue in the gap may prevent an accessory ossification center from allowing unification with the main portion of the patella. Additionally, the accessory fragment may be pulled aside by soft tissue structures similar to vastus medialis muscle or the retinacula, a mechanism which also inhibits bony union like in avulsion type fractures. Some authors report initial onset of clinical symptoms in those with bipartite patellae after trauma or overuse activities, which may be explained by “overstretching” of the fibrous gap.3,13

The subject of this case report experienced chronic pain at the gap between patella fragments bilaterally. The rehabilitation plan was multifaceted, including stretching and flexibility exercises that would

<table>
<thead>
<tr>
<th>Test</th>
<th>Final measures</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single leg squat</td>
<td>5 reps (without pain and knee giving way)</td>
<td>5 reps (without pain and knee giving way)</td>
<td></td>
</tr>
<tr>
<td>Leg crossover hop</td>
<td>402 cm</td>
<td>398 cm</td>
<td></td>
</tr>
<tr>
<td>One leg hop</td>
<td>104 cm</td>
<td>102 cm</td>
<td></td>
</tr>
<tr>
<td>Vertical jump</td>
<td>51 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triple hop, double leg jump</td>
<td>405 cm</td>
<td>405 cm</td>
<td></td>
</tr>
</tbody>
</table>
The medial bipartite patella is a rare finding but can be treated successfully as demonstrated in this case by a non-operative physical therapy approach including stretching and flexibility exercises, quadriceps strengthening, and ESWT.

**REFERENCES:**


**LIMITATIONS**

There were several limitations regarding this case report. The findings from a case report cannot be generalized to all subject populations. High quality randomized control trials are needed to document ESWT in treatment of bipartite patella pain. The subject was treated with conservative treatment before the described procedures, which could also have had some effect on the presentation or resolution of knee pain over time. At the beginning of treatment no objective measures of strength were taken, which would enhance the ability to determine changes in strength over time. However, the described therapy allowed the subject recovery to pain free status and return to preferred sport activities.

**CONCLUSIONS**

Even though only three typical types of bipartite patellae have been previously described, clinicians should be aware of the possibility of medial bipartite patella in cases of medial peripatellar knee pain.
ABSTRACT

**Background and Purpose:** Youth participation in basketball is on the rise, with basketball one of the top five participation sports in Australia. With increased participation there is a need for greater awareness of the importance of the pre-participation examination, including musculoskeletal screening and functional performance testing as part of a multidisciplinary approach to reducing the risk for future injuries. As majority of all basketball injuries affect the lower extremities, pre-participation musculoskeletal screening and functional performance testing should assess fundamental movement qualities throughout the kinetic chain with an emphasis on lower extremity force characteristics, specifically eccentric loading tasks. Thus, the purpose of this clinical commentary is to review the existing literature elucidating pre-participation musculoskeletal screening and functional performance tests that can be used as a framework for rehabilitation professionals in assessing basketball athletes’ readiness to safely perform the movement demands of their sport.

**Methods:** Relevant articles published between 2000 and 2016 using the search terms ‘musculoskeletal screening’, ‘functional testing’, ‘youth athletes’, and ‘basketball’ were identified using MEDLINE. From a basketball-specific perspective, several relevant musculoskeletal assessments were identified, including: the Functional Hop Test Combination, the Landing Error Scoring System, the Tuck Jump Assessment, the Weight-Bearing Lunge Test, and the Star Excursion Balance Test. Each of these assessments creates movement demands that allow for easy identification of inefficient and/or compensatory movement tendencies. A basic understanding of musculoskeletal deficits including bilateral strength and flexibility imbalances, lower crossed syndrome, and dominance-related factors are key components in determination of injury risk.

**Discussion:** Assessment of sport-specific movement demands through musculoskeletal screening and functional performance testing is essential for rehabilitation professionals to determine movement competency during performance of fundamental movements related to basketball performance. Youth athletes represent a unique population due to their developing musculoskeletal and neuromuscular systems and should undergo pre-participation musculoskeletal screening for identification of movement limitations. Such an approach to musculoskeletal screening and functional performance may assist in identifying injury risk and also be useful at the end of rehabilitation in determining readiness to return to sport models.

**Keywords:** Basketball, injury prevention, musculoskeletal screening, youth athletes

**Level of Evidence:** Level 5
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As such, a central component of athlete preparation is pre-participation musculoskeletal screening and functional testing.15-18 The National Athletic Trainers’ Association (NATA)17 highlights that musculoskeletal injury is a common cause of restriction of sports activities (i.e., lost training and game time); therefore, pre-participation musculoskeletal screening and functional testing should be directed towards detection of any underlying musculoskeletal limitations that might predispose an athlete to injury. While literature on sport-specific pre-participation musculoskeletal screening and functional testing protocols is limited,19-21 lower extremity and lower back symptoms appear to be common complaints.20 Screening movement quality throughout the kinetic chain emphasizing lower-extremity force interplay characteristics,7 specifically eccentric loading should be targeted. As such, rehabilitation professionals should not only possess a basic understanding of musculoskeletal deficits including bilateral strength and flexibility imbalances, lower crossed syndrome, and dominance-related factors which are key components in determination of injury risk, but should also be familiar with the incidence of injury (injury rate) and injury characteristics (injury type) related to basketball practice and games.

From a basketball-specific perspective, musculoskeletal assessments such as the Functional Hop Test Combination, the Landing Error Scoring System, the Tuck Jump Assessment, the Weight-Bearing Lunge Test, and the Star Excursion Balance Test allow for easy identification of inefficient and/or compensatory movement tendencies. However, to the authors’ knowledge there are no published basketball-specific pre-participation musculoskeletal screening and functional testing protocols.22 Therefore, the purpose of this clinical commentary is to review the existing literature elucidating pre-participation musculoskeletal screening and functional performance tests that can be used as a framework for rehabilitation professionals in assessing basketball athletes’ readiness to safely perform the movement demands of their sport.

INJURY RATES AND CHARACTERISTICS IN BASKETBALL

Injury Rates

For the purpose of this paper injury rates will be reported as the number of injuries per 1000 ath-
le exposures (AE), with AE defined as one athlete participating in one basketball practice or game when he or she is exposed to the possibility of injury. Amongst high school athletes, overall injury rates for girls are reported at 2.08 per 1000 AE (3.66 and 1.43, respectively, for competition and practice) and 1.83 per 1000 AE practice. When comparing the period of the season (pre-season versus in-season), injury rates are higher in the pre-season for both practice and games. Dick et al reported that pre-season injury rate in practice was almost 3.0 times higher than in-season practice injury rate in NCAA men’s basketball (7.5 versus 2.8 injuries per 1000 AE). Similar data is reported for female athletes, with pre-season practice injury rates more than twice as high as regular-season practice injury rates (6.8 versus 2.8 injuries per 1000 AE). The higher injury rates may be attributed to off-season deconditioning, increased training intensity and fatigue, inappropriate recovery, and pressure on players to earn starting positions. Collectively, with respect to playing position, the guard position accounted for the most injuries, followed by forward, and center.

Much higher injury rates are reported during professional basketball in both the National Basketball Association (NBA) (19.1- 19.3 per 1000 AE), and Women’s National Basketball Association (WNBA) (24.9 per 1000 AE). These injury rates are two-fold and three-fold higher, respectively, for men and women, than those reported in the NCAA. This may be explained by the combination of higher game intensity of the NBA/WNBA, with a more unpredictable and significantly greater physical competitive environment. Figure 1 displays injury rates with gender comparisons between NBA/WNBA, NCAA and high school basketball players.

Injury Characteristics

At the three levels of competition reviewed (high school, NCAA, NBA/WNBA), sprains are the most commonly reported injury representing between 28% and 52% of total injuries reported (Table 1). Gender comparisons demonstrate little difference in the instance of sprain injuries between female and male athletes at the collegiate and professional level. For example, NCAA data indicates that sprains account for 31% of injuries in females, compared to 30% of injuries in male players, with similar data reported for professional players (30.4% WNBA versus 29.9% NBA). However, at the high school level when practice and game-related data are combined, female athletes suffer more sprains than males representing 56% of overall injuries in female players versus 47% in male players. Game-related data only

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**Table 1.** Common basketball injuries combined across levels (high school, collegiate, semi-professional and professional) by play and gender

<table>
<thead>
<tr>
<th>Injury classification</th>
<th>Occurrence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sprains</td>
<td>28-52%</td>
</tr>
<tr>
<td>Overuse</td>
<td>22-39%</td>
</tr>
<tr>
<td>Strains</td>
<td>15-18%</td>
</tr>
<tr>
<td>Contusions</td>
<td>8-25%</td>
</tr>
<tr>
<td>Fractures</td>
<td>4-8%</td>
</tr>
</tbody>
</table>

Combined data: 9, 11, 13, 14, 23-25, 112
Given the implications of repeated jump landing (eccentric loading) on athletes with patellar tendinopathy, and non-contact ACL injury mechanisms, screening how an athlete lands is an important consideration. For example asymptomatic athletes with a patellar tendon abnormality display an altered landing strategy. Edwards et al reported altered hip movement strategy in patellar tendon abnormality (PTA) athletes. During the stop-jump task landing, athletes with a PTA displayed altered sequencing by landing with significantly greater knee flexion and extending their hips, which in turn may increase the tensile and compressive loads on the proximal part of the patellar tendon and contribute to the development of patellar tendinopathy. Furthermore, hip range of motion (ROM), knee joint angle at initial contact during the stop-jump task landing, as well as quadriceps flexibility were recently reported as substantial predictors of the presence of PTA, with patellar tendinopathy severity determined via the Victorian Institute of Sport Assessment (VISA) Scale, which may be used as an index of symptom severity (Appendix 1). Collectively, identification of altered landing strategies through an injury prevention through prediction framework could potentially identify those athletes who are at an increased risk of developing patellar tendinopathy and allow corrective movement strategies to be implemented.

Injury Prevention through Prediction

The ‘injury prevention through prediction’ approach aims to assess fundamental movement qualities in order to identify injury risk, as reduced movement quality is suggestive of higher injury risk, especially in youth athletes. Inclusion of movement competency assessment prior to performance testing may identify primary and secondary sources of movement dysfunction, which can lead to development of compensatory movement patterns, in turn leading to repeated micro trauma and muscular imbalances. By implementing an injury prevention through prediction framework, the rehabilitation professional can identify athletes at risk and introduce corrective exercises as part of a prehabilitation approach. Additionally, implementation of strategies such as functionally integrated movement preparation and prehabilitation is of value for injury prevention.
risk reduction and performance enhancement. The rationale behind such strategies relates to the concept of movement rehearsal, which is commonly integrated into prehabilitation and rehabilitation programs for the purpose of reducing injury risk, especially targeting control of the lumbo-pelvic-hip complex. In following the injury prevention through prediction philosophy the authors have implemented injury prevention initiatives which are deemed to be practical risk modification strategies that may reduce injury rates, especially in youth athletes.

**MUSCULOSKELETAL SCREENING FOR INJURY PREVENTION**

**Movement Screening**

Early reports of musculoskeletal screening aimed at injury risk reduction and improving athletic performance were centered on isolated assessments of muscular strength and flexibility as part of the pre-participation examination. However, such an approach to injury prevention did not assess the fundamental movement qualities related to athlete performance, as the body segments do not work in isolation during athletic movements. More recently, there has been a move away from such isolated assessments to integrated movement screening. Assessing an athlete’s movement competency, or the ability to perform fundamental movements related to athletic performance is considered by many to be a more appropriate examination of an athlete’s potential injury risk and readiness to train/compete. This integrated movement screening approach for injury prevention through prediction and performance enhancement assesses force interplay characteristics along the mobility/stability continuum, allowing determination of primary and secondary sources of movement dysfunction. While several movement screens have been developed to examine asymmetries in fundamental movement qualities, there appear to be three frequently reported considerations for physical therapists, athletic trainers and rehabilitation professionals; 1) time restraints when conducting movement screening on larger numbers of athletes; 2) does the movement screen assess the athletic movement patterns commonly seen in a competitive environment?; and 3) will the movement screen data provide specific exercise prescription information to assist in determining athlete loading parameters?

With this in mind, the Australian Institute of Sport (AIS), in consultation with Basketball Australia, developed a comprehensive basketball-specific movement screen that include five primary movement screens and four supplementary tests (Table 2). Each of the five primary movement screens have been described elsewhere. The primary movement screens are subjectively scored on a scale of 1 to 3 (1 = cannot complete exercise without major flaws; 2 = can complete exercise but with some minor flaws; 3 = can execute exercise with technical proficiency). Therefore, the maximum score (15 points) would be awarded to a technically proficient athlete demonstrating no flaws, with the criterion cut-off score of less than 12 points (80%) classified as a fail. Additionally, the athlete is required to successfully pass the

**Table 2. Basketball-specific movement screen - Australian Institute of Sport/Basketball Australia**

<table>
<thead>
<tr>
<th>Primary movement screens</th>
<th>Supplementary tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Back squat with dowel</td>
<td>1) Single-leg glute bridge – 12 repetitions @</td>
</tr>
<tr>
<td>2) Overhead squat with dowel</td>
<td>2) Push-up – 6 repetitions</td>
</tr>
<tr>
<td>3) In-line lunge with dowel</td>
<td>3) Prone plank hold – 1 minute</td>
</tr>
<tr>
<td>4) Box drop to landing - 30cm box</td>
<td>4) Single leg calf rise – 20 repetitions @</td>
</tr>
<tr>
<td>5) Single-leg hop plus stick landing</td>
<td></td>
</tr>
</tbody>
</table>

**Primary movement screens:** 5 repetitions are performed for each screen with screens 3 and 5 performed on both left and right sides. The lower score of the two sides is recorded and is counted toward the total; however it is important to note imbalances that are present between right and left sides. **Supplementary tests:** Repetitions are outlined for each test with tests 1 and 4 performed on both left and right sides. **Abbreviations:** @ = each side. Source: Legg.
Hop and Jump Assessments

Given the dynamic movement patterns in basketball, which involve multiple directional changes (vertical, horizontal, and/or lateral) and jump landings, the assessment of an athlete’s lower extremity neuromuscular control through multidirectional hop and jump assessments have received significant research interest. \(^{56-59}\) Hewett and colleagues \(^{60}\) recommend that in high-risk jumping and cutting sports, such as basketball, youth athletes need to demonstrate proficiency in neuromuscular performance of such skills. This is of significant importance given that in basketball repetitive directional changes are not always performed using a bilateral take-off or landing. \(^{57}\) The use of multidirectional hop and jump assessments may allow for greater observation of muscle imbalances that could affect the success of the movement pattern, thereby providing rehabilitation professionals with data that can be used for both training program design and monitoring, and/or assessment of neuromuscular control deficits and injury risk.

Several hop and jump assessments are described in the literature as reliable, inexpensive, and easily administered measures of neuromuscular control in both athletic and rehabilitation populations. These include hop tests, \(^{56,61,62}\) landing error scoring system (LESS), \(^{63,65}\) and tuck jump assessment. \(^{58,66}\) Commonly reported neuromuscular control deficits observed in athletes during hop and jump assessments include high-force landings and bilateral imbalances in landing force, \(^{60}\) limb dominance-related issues [ligament dominance, quadriceps dominance, leg dominance, for extensive review see Myer et al \(^{47}\)], excessive valgus knee position (medial knee collapse), \(^{68}\) and trunk dominance. Commonly used hop and jump assessments recommended for basketball athletes are described below.

**Four Functional Hop Test Combination**

The four functional hop test combination provide valuable information when assessing strength, power, and neuromuscular control of the lower extremity. \(^{69}\) Importantly, such tests allow observation of the lower extremity under eccentric loading and quantification of the limb symmetry index. A limb symmetry index score of less than 85% is considered abnormal. \(^{70,71}\) The following instructions outline how to conduct the four functional hop test combinations \(^{56,61,62,72}\) shown in Figure 2.

**How to Conduct the Four Functional Hop Test Combination**

1. **Single-leg Hop for Distance** (Figure 2a). The athlete stands on the designated testing leg, with their toe...
on the starting line and instructed to hop as far as possible forward and land on the same leg. Measure the distance hopped from the starting line to the point where the athlete’s heel lands. The athlete is encouraged to ‘stick and hold’ the landing position with control and minimal body sway for a minimum of three seconds.

2. **Triple Hop for Distance (Figure 2b).** Athletes begin standing on the designated testing leg, with their toe on the starting line and are instructed to take three maximal hops forward with the designated leg. Measure the distance hopped from the starting line to the point where the athlete’s heel lands on completing the third hop. Encourage the athlete to ‘stick and hold’ the final landing position with control and minimal body sway for a minimum of three seconds.

3. **Crossover Triple Hop for Distance (Figure 2c).** Athletes begin by standing on the same side of the centre tape as the designated testing leg, with their toe on the starting line. For example, if athletes were hopping with their right leg, stand on the right side of the tape. Athletes are instructed to take three consecutive maximal hops forward with the designated leg, crossing over the strip of tape each time in a zig-zag pattern. Measure the distance hopped from the starting line to the point where the athlete’s heel lands on completing the third hop. Athletes are encouraged to ‘stick and hold’ the final landing position with control and minimal body sway for a minimum of three seconds.

4. **Six-meter One-legged Timed Hop (Figure 2d).** Athletes begin standing on the designated testing leg, with their toe on the starting line. On the command of “3, 2, 1, go” the athlete hops the 6-meter distance as quickly as possible with the designated leg. Timing ends when the athlete crosses the 6-meter finish line.

**Landing Error Scoring System (LESS)**
The landing error scoring system (LESS) is reported to be a reliable screening tool developed to identify individuals at increased risk for non-contact ACL injury through evaluation of landing mechanics associated with the drop box vertical jump (DBVJ) test. The LESS evaluates 17 jump-landing characteristics following a DBVJ test and is scored by reviewing a recorded video of the jump landing task. A higher LESS score indicates poor technique in jump landing; a lower LESS score indicates better jump-landing technique. Most recently, Padua and colleagues reported that elite youth soccer players with LESS scores of five or more were at a higher risk for sustaining ACL injuries than athletes with LESS scores less than five, suggesting that five was the optimal cut-off point for the LESS for elite youth field and court sport athletes. However, a practical limitation for rehabilitation professionals is that the LESS is not assessed in real time and requires the use of video cameras. This led to the development of the Landing Error Scoring System-Real Time (LESS-RT), which examines 10 jump-landing characteristics (Table 3) and is scored over four trials of the jump-landing task.

**How to conduct the LESS-RT**
1. The athlete begins standing on a 30-cm-high box placed at a distance of half the body height away from a target landing area, which is marked on the ground;
2. Instruct the athlete to jump forward so that both limbs leave the box simultaneously, to land in target landing area, and to jump as high as they can after their initial landing from the box;
3. A successful jump is characterized by the following as outlined in the LESS-RT scoring sheet presented in Table 4;
   a. both feet simultaneously leaving the box;
   b. jumping forward off the box without a large upward motion after take-off from the box to reach the target landing area below; and
   c. completing the jump in a fluid motion (no pause in movement of body’s center of mass after making contact with the ground until take-off for subsequent jump).
4. If a jump is unsuccessful the athlete repeats the DBVJ without additional instructions.

**The Tuck Jump Assessment**
Given the repetitive jump and landing actions in basketball, the tuck jump assessment, as suggested by
### Table 3. Definitions of Individual Items in the LESS-REAL TIME (LESS-RT)

<table>
<thead>
<tr>
<th>LESS-RT item</th>
<th>Definitions</th>
<th>Example Score</th>
<th>View position</th>
<th>Jump trial which item is scored</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Stance width</td>
<td>If the subject lands with a wide or narrow stance when evaluated from the frontal plane, he/she receives an error. An error is only scored if the stance is observed to be very wide or very narrow (+1).</td>
<td>+1</td>
<td>Front</td>
<td>Jump trial</td>
</tr>
<tr>
<td>2. Maximum foot-rotation position</td>
<td>If a subject’s feet are moderately externally rotated or slightly internally rotated at any point during the jump landing, he/she receives an error (+1).</td>
<td>+1</td>
<td>Front</td>
<td>Jump trial</td>
</tr>
<tr>
<td>3. Initial foot-contact symmetry</td>
<td>If one foot lands before the other or if one foot lands heel-to-toe and the other lands toe-to-heel, the subject receives an error (+1).</td>
<td>0</td>
<td>Front</td>
<td>Jump trial</td>
</tr>
<tr>
<td>4. Maximum knee-valgus angle</td>
<td>If the subject moves into a small amount of knee valgus, he/she receives an error (+1). If the subject moves into a large amount of knee valgus, he/she receives an error (+2).</td>
<td>+1</td>
<td>Front</td>
<td>Jump trial</td>
</tr>
<tr>
<td>5. Amount of lateral trunk flexion</td>
<td>If the subject is leaning to the right or left side so that the trunk is not vertical in the frontal plane, he/she receives an error (+1).</td>
<td>+1</td>
<td>Front</td>
<td>Jump trial</td>
</tr>
<tr>
<td>6. Initial landing of feet</td>
<td>If the subject lands heel to toe or with a flat foot, he/she receives an error (+1).</td>
<td>0</td>
<td>Side</td>
<td>Jump trial</td>
</tr>
<tr>
<td>7. Amount of knee-flexion displacement</td>
<td>If the subject goes through a small (+2) or average amount (+1) of knee flexion displacement, he/she receives an error.</td>
<td>+1</td>
<td>Side</td>
<td>Jump trial</td>
</tr>
<tr>
<td>8. Amount of trunk-flexion displacement</td>
<td>If the subject goes through a small (+2) or average amount (+1) of trunk flexion displacement, he/she receives an error.</td>
<td>+1</td>
<td>Side</td>
<td>Jump trial</td>
</tr>
<tr>
<td>9. Total joint displacement in the sagittal plane</td>
<td>If the subject goes through large displacement of the trunk and knees, then score soft (0). If the subject goes through an average amount of trunk and knee displacement, then score average (+1). If the subject goes through a small amount of any trunk and knee displacement, then score stiff (+2).</td>
<td>0</td>
<td>Side</td>
<td>Jump trial</td>
</tr>
<tr>
<td>10. Overall impression</td>
<td>Score excellent (0) if the subject displays a soft landing and no frontal-plane motion at the knee. Score poor (+2) if the subject displays a stiff landing and large frontal-plane motion at the knee, or only large frontal-plane motion at the knee. All other landings, score average (+1).</td>
<td>+1</td>
<td>N/A</td>
<td>Jump trial</td>
</tr>
</tbody>
</table>

Adapted from Pudua and colleagues\(^{65}\)

LESS TOTAL +7 Note: A lower score is better

### Table 4. Scoring sheet for the Landing Error Scoring System-Real Time (LESS-RT)

<table>
<thead>
<tr>
<th>Frontal plane motion</th>
<th>Sagittal plane motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Stance width</td>
<td>1. Initial landing of feet</td>
</tr>
<tr>
<td>□ Normal (0)</td>
<td>□ Toe to heel (0)</td>
</tr>
<tr>
<td>□ Wide (1)</td>
<td>□ Heel to toe (1)</td>
</tr>
<tr>
<td>□ Narrow (1)</td>
<td>□ Flat (1)</td>
</tr>
<tr>
<td>□ Normal (0)</td>
<td>□ Large (0)</td>
</tr>
<tr>
<td>□ Externally rotated (1)</td>
<td>□ Average (1)</td>
</tr>
<tr>
<td>□ Internally rotated (1)</td>
<td>□ Small (2)</td>
</tr>
<tr>
<td>3. Initial foot contact</td>
<td>3. Amount of trunk flexion displacement</td>
</tr>
<tr>
<td>□ Symmetric (0)</td>
<td>□ Large (0)</td>
</tr>
<tr>
<td>□ Not symmetric (1)</td>
<td>□ Average (1)</td>
</tr>
<tr>
<td>4. Maximum knee valgus angle</td>
<td>□ Small (2)</td>
</tr>
<tr>
<td>□ None (0)</td>
<td>4. Total joint displacement in sagittal plane</td>
</tr>
<tr>
<td>□ Small (1)</td>
<td>□ Soft (0)</td>
</tr>
<tr>
<td>□ Large (2)</td>
<td>□ Average (1)</td>
</tr>
<tr>
<td>5. Amount of lateral trunk flexion</td>
<td>□ Stiff (2)</td>
</tr>
<tr>
<td>□ None (0)</td>
<td>5. Overall impression</td>
</tr>
<tr>
<td>□ Small to moderate (1)</td>
<td>□ Excellent (0)</td>
</tr>
<tr>
<td></td>
<td>□ Average (1)</td>
</tr>
<tr>
<td></td>
<td>□ Poor (2)</td>
</tr>
</tbody>
</table>

Adapted from Pudua and colleagues\(^{65}\)
Ankle Dorsiflexion Range of Motion: Weight-Bearing Lunge Test (WBLT)

In sports such as basketball, poor landing technique has been linked to both initial injury and re-injury. Risk for such injuries may be reduced by identifying key characteristics that inhibit correct landing technique. The amount of ankle dorsiflexion range of motion (ROM), as well as the strength of the muscles performing plantar flexion are considered the most important components in the shock absorption phase during landing. Restricted ankle dorsiflexion ROM during landing is accompanied by decreased knee-flexion and hip-flexion resulting in “stiff” landings characterized by an erect landing posture and diminished sagittal-plane movement of the LE's resulting in greater ground reaction forces. Such biomechanical factors are considered risk factors for anterior cruciate ligament (ACL) injury, and Fong et al reported that greater passive ankle dorsiflexion ROM was not only associated with greater knee-faction movement but also smaller ground reaction forces during jump landing, which reduces strain on the skeletal structures as well as injury risk.

Basketball players lacking adequate ankle dorsiflexion ROM are nearly five times more likely to reinjure an ankle after a prior ankle injury. Backman and Danielson reported that ankle dorsiflexion ROM less than 36.5 degrees, as measured by a gravity inclinometer, predisposes elite junior basketball player to patellar tendinopathy. Hoch and colleagues reported a significant moderated correlation (r = 0.53; p < 0.001) between ankle dorsiflexion ROM and Star Excursion Balance Test - anterior reach (SEBT-AR) in healthy adults with no history of lower extremity injury. Hoch et al confirmed that patients with chronic ankle instability (CAI) demonstrated significantly less ankle dorsiflexion ROM and impairments in dynamic postural control compared to healthy controls. The authors concluded that ankle dorsiflexion ROM significantly influences dynamic balance, highlighting the importance of assessing ankle dorsiflexion ROM. A simple and practical measure of ankle dorsiflexion ROM is the weight-bearing lunge test (WBLT), which has been reported to have excellent inter-tester and intra-tester reliability. The WBLT method utilizes the knee-to-wall principle with the athlete placing the foot perpendicular to a wall and lunging forward so

How to Conduct the Tuck Jump Assessment

1. The athlete starts in an athletic stance position with feet shoulder width apart. Initiate the jump with a slight crouch downward while extending their arms behind the body.

2. Simultaneously jumping and swinging the arms forward the athlete pulls the knees up toward the chest as high as possible. Knees should be parallel at the top of the jump.

3. Landing softly on the toes, the athlete should immediately attempt the next tuck jump.

4. Repetitions should be performed with maximal effort and as quickly as possible for 10 seconds. The test is terminated if the athlete cannot control the high landing force or if they demonstrate excessive knee valgus on landing.

Myer and colleagues may be useful for the identification of lower extremity jump and landing error technique. Insufficient neuromuscular control of lower limb biomechanics, particularly the knee joint, may predispose youth athletes, especially female athletes, to higher injury risk. The tuck jump assessment challenges muscular force interplay characteristics of the lower extremity, including explosive triple extension of the hips, knees, and ankles on take-off, force absorption through the hips, knees, and ankles on landing, and utilization of the stretch shortening cycle. Extensive work by Myer and colleagues highlights the practical application of the tuck jump assessment in identifying lower extremity dysfunction such as decreased neuromuscular control, trunk dominance, high risk landing patterns, excessive knee valgus, and increased risk of anterior cruciate ligament injury. The tuck jump assessment may also be used as a monitoring tool to track changes in dynamic lower extremity biomechanics by addressing four fundamental areas: 1) correct posture (i.e., chest over knees) throughout the jump, 2) following a purely vertical trajectory without any medial/lateral or anterior/posterior deviations, 3) soft landings, including toe-to-heel rocking and bent knees, and 4) instant recoilation preparation for the next jump. Criteria may be grouped into the neuromuscular risk factor dominance categories presented in Table 5.
2. The heel should not be lifted off from the floor, and the subtalar joint should be locked. Look out for exaggerated hip flexion and inhibited knee flexion;

3. The foot is sequentially moved further away from the wall until knee can only make slight contact with the wall while the foot remains flat on the ground;

4. The knee touches the wall (Figure 3). Therefore, we recommend that the WBLT be included in the musculoskeletal screen for basketball athletes.

**How to Conduct the Weight-Bearing Lunge Test**

1. The athlete places the test foot on a tape measure perpendicular to the wall and lunges forward so the knee touches the wall;  

2. The heel should not be lifted off from the floor, and the subtalar joint should be locked. Look out for exaggerated hip flexion and inhibited knee flexion;  

3. The foot is sequentially moved further away from the wall until knee can only make slight contact with the wall while the foot remains flat on the ground;

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**Table 5. The Tuck Jump Assessment criteria**

<table>
<thead>
<tr>
<th>Tuck Jump Assessment</th>
<th>Errors</th>
<th>Neuromuscular deficits</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee and thigh motion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Lower extremity medial knee collapse landing</td>
<td></td>
<td>Ligament dominance</td>
<td></td>
</tr>
<tr>
<td>2. Thighs do not reach parallel at peak jump height</td>
<td></td>
<td>Trunk dominance/core dysfunction</td>
<td></td>
</tr>
<tr>
<td>3. Thighs not equal side-to-side during jump flight</td>
<td></td>
<td>Leg dominance/residual injury deficit</td>
<td></td>
</tr>
<tr>
<td>Foot position during landing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Foot placement not shoulder width apart</td>
<td></td>
<td>Ligament dominance</td>
<td></td>
</tr>
<tr>
<td>5. Foot placement not parallel (front to back)</td>
<td></td>
<td>Leg dominance/residual injury deficit</td>
<td></td>
</tr>
<tr>
<td>6. Foot contact timing not equal</td>
<td></td>
<td>Leg dominance/residual injury deficit</td>
<td></td>
</tr>
<tr>
<td>7. Excessive landing contact noise</td>
<td></td>
<td>Quadiceps dominance</td>
<td></td>
</tr>
<tr>
<td>Plyometric technique</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Pause between jumps</td>
<td></td>
<td>Trunk dominance/core dysfunction</td>
<td></td>
</tr>
<tr>
<td>9. Does not land in same footprint (deviation in flight)</td>
<td></td>
<td>Trunk dominance/core dysfunction</td>
<td></td>
</tr>
<tr>
<td>10. Technique declines prior to 10 s</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Score any deviations from correct performance before, during, and after the performance of several tuck jumps over 10 seconds. More checked boxes indicates poorer technique, and also suggests the areas upon which the athlete should concentrate during training. Adapted from Myer and colleagues. Image taken by SPB. Basketball WA High Performance Program.
The SEBT protocol can be time-consuming due to the number of trials required for each of the eight directions (six practice attempts, three test trials). As such, Hertel and colleagues argue that there is redundancy in testing all eight reach directions, with the modified three direction SEBT (referred to as the Y Balance Test) more applicable. The Y-Balance Test (YBT) incorporates three reach components of the SEBT (anterior, posteromedial and posterolateral) with research primarily focused on reach asymmetries and composite score which can be used to identify potential injury risks in athletic populations.

The SEBT/YBT appear to be valuable musculoskeletal screens that contribute to the identification of movement dysfunction in basketball players. Bressel et al reported that NCAA Division I female basketball players display both inferior static balance compared with gymnasts and impaired dynamic balance compared with soccer players as determined by the SEBT. Additionally, Plisky et al predicted lower extremity injuries in high school basketball athletes by utilizing a modified-SEBT (3 reach directions - anterior, posteromedial and posterolateral). The authors reported that high school basketball players with right versus left lower extremity anterior reach differences greater than 4cm were 2.5 times more likely to sustain a lower extremity injury. Females with a composite reach distance less than 94% of their limb length were 6.5 times more likely to sustain a lower extremity injury. Therefore, the practical relevance of the SEBT/YBT for physical therapists, athletic trainers and rehabilitation professionals' centers on its potential application as a prediction tool to identify functional deficits related to the trunk and lower extremity.

Analyzing total reach distance normalized to the limb length (reach distance/leg length) x100, and calculating total composite score (sum of the best reach distance for the three directions) divided by three times the leg length allows identification of high-risk athletes, and individualization of corrective strength and conditioning training programs. Additionally, this data may be used to as part of a return to play criteria for athletes following lower extremity injury, with the achievement of minimum standards required before returning to on-court training or competitive drills. For example, an athlete must

4. This position is maximum ankle dorsiflexion ROM and the distance from the great toe to the wall is measured in centimeters (each centimeter corresponds to approximately 3.6 degrees of ankle dorsiflexion).

5. Less than 10 cm is considered restricted.

**Star Excursion Balance Test and Y-Balance Test**

The Star Excursion Balance Test (SEBT) is a multidirectional test of static balance and dynamic postural control that involves balancing on one leg and reaching maximally with the other leg in eight different directions including three anterior, two lateral, and three posterior. The SEBT is commonly used in athletic research settings during assessment of key characteristics of static and dynamic balance, including ankle dorsiflexion, knee flexion, and hip flexion ranges of motion and strength, proprioception, and neuromuscular control. The SEBT is a sensitive and valid musculoskeletal screening tool, with reduced SEBT performance evident in conditions such as chronic ankle instability, anterior cruciate ligament (ACL) deficiency, and patellofemoral pain syndrome. Test-retest reliability and response stability of the SEBT ranges from 0.89 to 0.93 with method error coefficient of variation of 3.0% to 4.6%, suggesting good measurement stability.

The SEBT protocol can be time-consuming due to the number of trials required for each of the eight directions (six practice attempts, three test trials).5

As such, Hertel and colleagues argue that there is redundancy in testing all eight reach directions, with the modified three direction SEBT (referred to as the Y Balance Test) more applicable. The Y-Balance Test (YBT) incorporates three reach components of the SEBT (anterior, posteromedial and posterolateral) with research primarily focused on reach asymmetries and composite score which can be used to identify potential injury risks in athletic populations.
achieve a limb symmetry score of less than 4 cm difference between lower extremities in the anterior reach direction. Finally, a recent systematic review of measurement properties and correlation with injury by Hegedus and colleagues reported that there is strong evidence that the modified three-direction SEBT/YBT can identify injury risk in field and court sport athletes, with both a composite reach score difference of less than 94% and an anterior reach difference of 4 cm or greater being associated with increased injury risk. As such, we recommend that the YBT be incorporated as a musculoskeletal screening assessment. Additionally, the YBT could be prescribed as a balance and postural stability movement preparation task to develop hip strength, postural awareness, and proprioception potentially reducing risk of lower extremity injury.

How to Conduct the Modified Three-direction SEBT and Y Balance Test

Modified Three-direction SEBT

1. Construct a “Y” by securing three tape measures on the ground, one oriented anteriorly (ANT) to the apex and the other two aligned at 135 degrees to this in the posteromedial and posterolateral directions (Figure 4). Each length of tape should be between 1.8-2.5m.

2. Instruct the athlete to stand in the center of the Y barefoot with an equal portion of the stance foot to the anterior and posterior of the middle of the Y (this is a fixed position for all three reach attempts) while performing series of maximal reaches along the three vectors with the opposite leg without compromising the base of support;

3. Using the most distal part of the foot of the reach limb, touch the ground lightly with the toes without bearing weight through the reach limb and return to a standing position at the start;

4. Maximum reach distances are measured from the start point to the point of maximum reach at the toe.

Y-Balance Test (Lower quarter)

1. Have the athlete stand on the elevated central footplate with the great toe lined up with the red line on the commercially available YBT device (Y Balance Test, Move 2 Perform, Evansville, IN);

2. The athlete pushes the reach block with the foot in each of the three directions by touching the side of the reach plate and not bearing weight on the reaching limb;

3. The maximum reach distance is recorded as the point at which the reach block rested when the subject had returned to the start position after carrying out the reach. The subject is not allowed to accelerate the reach block.

Instruct the athlete to complete a familiarization trial for all three targets on both legs. Given the times contraints placed on rehabilitation professionals, the authors support the recommendation in reducing the number of practice attempts from six to four in a group/team setting. A trial is classified as invalid if the participant removed the hands from the hips, did not return to the start position, applied sufficient weight through the reach foot so as to gain an increase in reach distance (SEBT), placed the reach foot on the ground either side of the line or tube, raised or moved the stance foot during the test, or kicked the plate with the reach foot to gain more distance (YBT).

For the most accurate results Gribble et al suggested that the recorded reach scores should be normalized in relationship to limb length. This is recommended in a group setting to better compare
individual athletes’ scores and diminish the influence of height on reach distance. The athlete’s limb length is measured (using a standard tape measure) from the anterior superior iliac spine (ASIS) to the middle of the medial malleolus while the subject is supine. Scores are normalized to limb length by calculating the maximal reach distance (%MAXD) using the formula (Reach distance/limb length) × 100 = % MAXD. In addition, the composite score is determined by adding the greatest reach attempt from all three directions and dividing this sum by three times the limb length to provide a comprehensive overview of the athlete’s overall performance on the test. Consideration must be given to the fact that reach distances are likely affected by which sport the athlete participate in and by gender. We recommend that the YBT comparisons occur with norms by gender and sport. Table 6 presents suggested normative reach values for athletes performing the YBT based on our previous work with elite surfers.

**Balance Error Scoring System**

The Balance Error Scoring System (BESS) evaluates static bilateral and unilateral balance qualities on firm and unstable surfaces, consisting of three stances: double-leg stance (hands on the hips and feet together), single-leg stance (standing on the nondominant leg with hands on hips), and tandem stance (nondominant foot behind the dominant foot). Balance tests are performed on a firm surface and/or a foam surface with the eyes closed. Errors are counted during each 20-second trial with errors defined as opening the eyes, lifting the hands off hips, stepping, stumbling or falling out of position, lifting the forefoot or heel, abducting the hip by more than 30 degrees, or failing to return to the test position in more than five seconds. The BESS has primarily been used to identify individuals with functional ankle instability amongst collegiate athletes, while more recently there is interest in the BESS as a sideline environment concussion testing tool for assessing an athlete’s balance abilities. The BESS is reported to have moderate to good reliability (intraclass correlations 0.87-0.98) in assessing static balance. However, from a practical perspective the two-legged stance position may be redundant as it failed to illustrate significant variance. Hunt and colleagues found that removing the two leg stance improved the reliability of the BESS and resulted in an intraclass reliability coefficient of 0.88.

Poor static balance performance and increased postural sway measures have been associated with higher incidence of ankle sprains in high school basketball players. McGuine and colleagues utilized a modified BESS (Romberg test, barefoot) while on a force platform (NeuroCom, Clackamas, OR) to quantify postural sway velocity (the distance, measured as degrees of sway [°S] of the center of gravity away from the stable position per time) in 210 high school basketball athletes (119 male, 91 female). Each trial was performed for 10 seconds, with the total °S produced during the trial divided by 10 to produce a score represented as COG degrees of sway per second (°S/S). The authors found that players with higher postural sway scores (poor static balance) had

### Table 6. Reach distance values for athletes performing the Y-Balance Test

<table>
<thead>
<tr>
<th>Directions</th>
<th>Reported Values</th>
<th>Normalized Reach Scores</th>
<th>Recommended Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plisky et al. 87</td>
<td>de Noronha et al. 113</td>
<td>Plisky et al. 154</td>
</tr>
<tr>
<td>Anterior (cm)</td>
<td>78.2 ± 8.2</td>
<td>83.5 ± 7.0</td>
<td>72.9 ± 5.8</td>
</tr>
<tr>
<td>Posteromedial (cm)</td>
<td>107.0 ± 11.7</td>
<td>85.5 ± 9.7</td>
<td>114.9 ± 7.3</td>
</tr>
<tr>
<td>Posterolateral (cm)</td>
<td>100.4 ± 12.0</td>
<td>89.8 ± 9.7</td>
<td>112.3 ± 6.5</td>
</tr>
<tr>
<td>Composite Score (%)</td>
<td>100.9 ± 8.4%</td>
<td>107.5 ± 3.5%</td>
<td></td>
</tr>
</tbody>
</table>

Expressed as mean ± standard deviation. Recommended values expressed as mean of normalized reach scores.

---

**Note:** The table and text are from a research paper discussing the Y-Balance Test and Balance Error Scoring System (BESS) in sports physical therapy. The table provides suggested normative reach values for athletes performing the Y-Balance Test based on previous work with elite surfers. The BESS evaluates static balance with three stances: double-leg stance, single-leg stance, and tandem stance. Poor static balance performance is associated with increased incidence of ankle sprains in high school basketball players.
2. For each test condition the subject close his or her eyes and record the number of errors observed in 20 seconds;

3. Errors include opening the eyes, taking the hands off hips, any movement from initial stance position (stumble, step), lifting the forefoot or heel, excessive hip rotation in non-stance leg (abducting hip by >30°) or not returning to test position in a time period of five seconds;

4. The average of three trials be used to enhance reliability of the test and to familiarize the athlete;

5. Table 7 describes the stance positions and the measurement associated with each position. We recommended rehabilitation professionals video record each test and review the video and revise the score at a later date for greatest accuracy.

**PRACTICAL APPLICATIONS**

Of importance to rehabilitation professionals is the establishment of valid and reliable pre-participation musculoskeletal screening and functional testing protocols aimed at identifying injury risk in athletes. This must take into consideration not only the sport-specific game demands but also the developmental stage of the athlete. Given the potential influence of force interplay characteristics on postural demands during basketball game-play situations that frequently involve high intensity change of directions, dynamic tests that challenge postural control and balance allow identification of movement limitations in basketball athletes compared nearly seven times as many ankle sprains than those with better postural control. Conversely, players with low-sway scores (good balance) may have an enhanced risk reduction mechanism (Figure 5).

**How to Conduct the Modified Balance Error Scoring System**

1. Have the athlete complete the test under four conditions (2 stance positions – (i) tandem stance: non-dominant foot behind dominant foot; and (ii) single leg stance) on 2 surfaces (firm/flat surface and a foam surface);

2. Figure 5. Distribution of ankle sprain injuries per 1,000 exposures according to compilation sway balance scores between the low-sway, mod-sway, and high-sway groups (p = 0.0002). Figure adapted from McGuine and colleagues.

3. Table 7. Description of stance positions for the Balance Error Scoring System.

<table>
<thead>
<tr>
<th>Stance Position</th>
<th>Description</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Two-Legs</td>
<td>• Stand with feet together&lt;br&gt;• Hands on hips&lt;br&gt;• Eyes closed</td>
<td>Count/record number of errors in 20 seconds</td>
</tr>
<tr>
<td>a) firm surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) foam surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Tandem</td>
<td>• Stand with non-dominant foot behind dominant foot (heel to toe)&lt;br&gt;• Hands on hips&lt;br&gt;• Eyes closed</td>
<td>Count/record number of errors in 20 seconds</td>
</tr>
<tr>
<td>a) firm surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) foam surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Single-leg</td>
<td>• Stand on the non-dominant foot&lt;br&gt;• Hands of hips&lt;br&gt;• Eyes closed</td>
<td>Count/record number of errors in 20 seconds</td>
</tr>
<tr>
<td>a) firm surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) foam surface</td>
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</table>
to isolated assessments of muscle function. Collectively, the musculoskeletal screens and functional performance tests described in this clinical commentary may allow easy identification of inefficient and/or compensatory movement tendencies in athletes, and provide an inexpensive and practical means in determining athletes that may be at risk. The recommended protocols are not limited to rehabilitation professionals during pre-participation screening, such an approach to musculoskeletal screening and functional performance may also be useful during and following rehabilitation in determining readiness to return to sport. While the authors have employed such protocols with elite youth and elite senior male and female athletes as part of a multidisciplinary approach to injury prevention, further studies with athletes from different sports and of various ages are required to quantify the relationships between pre-participation musculoskeletal screening results, functional performance testing, and injury risk. This clinical commentary offers evidence informed choices for a battery of musculoskeletal screens and functional performance tests used by the authors from a basketball-specific perspective. The authors acknowledge that there is limited research to support or refute their combined use specifically for basketball athletes.

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ABSTRACT

Background: Appropriate assessment and interventions for breathing patterns prior to assessment of the patient's musculoskeletal complaint may be beneficial. Breathing pattern disorders (BPDs) are remediable and influenced by biochemical, biomechanical, psychological, and/or unknown factors. The purpose of this clinical commentary is to demonstrate the integration of a BPD assessment into a standard clinical musculoskeletal orthopedic examination.

Clinical Assessment: The observation of a patient's breathing pattern begins when they enter the clinic, is followed by palpation and orthopedic tests, which allows for proper classification of BPDs.

Outcomes: Disease-oriented measures guide the assessment and classification of BPD, while patient-oriented measures describe clinically important differences among patient values.

Classification: There are many possible variations of classifications of BPD, however, six primary dysfunctions found in the literature have become the foundation of the BPD assessment.

Discussion and Conclusion: Restoring proper breathing mechanics and neuromuscular motor control patterns during breathing may result in a decrease in pain, improved patient outcomes, and overall patient well being associated with their primary musculoskeletal complaint. A comprehensive evaluation of breathing patterns, as a part of an orthopedic examination, may guide a clinician in providing effective and appropriate treatments to decrease pain and improve function.

Level of Evidence: 5

Keywords: Dysfunctional movement patterns; startle reflex; musculoskeletal pain
INTRODUCTION AND BACKGROUND

The evaluation and treatment of breathing pattern disorders (BPDs) may be a missing component in the treatment of musculoskeletal pain. Breathing mediates neuromusculoskeletal responses through its influence on the autonomic nervous system (ANS) and the central nervous system (CNS). Breathing can be affected by biomechanical, biochemical, psychological, physiological, and/or unknown factors. Various examination and treatment paradigms such as, dynamic neuromuscular stabilization, selective functional movement assessment, Buteyko method, and the Janda approach support the concept that breathing is the foundation of allostasis and functional movement. In a typical rehabilitation clinic, assessing breathing patterns may seem like a foreign concept due to the lack of emphasis placed on breathing in the traditional patient examination. However, breathing assessment may be an overlooked and essential tool to address a patient’s primary complaint of musculoskeletal pain. The purpose of this clinical commentary is to demonstrate the integration of a breathing pattern disorder (BPD) assessment into a standard clinical musculoskeletal orthopedic examination. Part II of this commentary will describe the assessment and treatment of patients with BPDs and its effect on their primary complaint of musculoskeletal pain.

A BPD is a dysfunction, not a disease, which in most cases is remediable through rehabilitation and neuromuscular re-education. Symptoms of BPDs can mimic other diseases, often making diagnosis and treatment of BPDs challenging. Clinicians may not always be able to classify a patient into a specific BPD; therefore, must know the etiological features that can cause less than optimal breathing patterns.

Paradoxical breathing, where the abdomen draws in during inhalation and out on exhalation, is often considered the most severe BPD. The theoretical result of this BPD is inadequate tidal volume and over activation of the scalenes and other accessory breathing muscles of the upper chest. The subsequent insufficient exchange of gasses is thought to lead to respiratory distress and musculoskeletal imbalances. Similarly, BPDs known as hyperventilation syndrome and tachypnea alters the body’s pH producing respiratory alkalosis; which results in an array of symptoms including headache, dizziness, chest pain, trouble sleeping, breathlessness, light sensitivities, exhaustion, and cramps. The cause of paradoxical breathing and hyperventilation syndrome is not always known, but can be associated with stress or an emotional response to a traumatic situation. The secondary symptoms of BPDs, such as frequent yawning, inability to take a deep breath, fatigue and panic attacks, may resolve with an appropriate intervention.

FUNCTIONAL BREATHING

The CNS is immature in infants, allowing muscular and breathing patterns to develop sequentially in a genetically pre-determined pattern. The diaphragm attains its position in the transverse plane between four to six months after birth, and costal breathing is fully established at six-months. Once the position of the diaphragm is established it contributes to the development of stability of the spine and core, allowing the baby to roll, crawl, sit, stand, and begin to walk. Breathing requires synchronized concentric activity of the diaphragm and pelvic floor, as well as eccentric activity of all muscles that insert into the thorax and abdominal wall muscles. Improper sequencing during an abdominal breath can alter motor control patterns of postural muscles and spinal stabilizers resulting in pain and/or dysfunction. Therefore, a functional breathing pattern can provide the clinician with a unique perspective into the coordination and maturation of the CNS.

Many muscles assist in the ability to take a breath. The primary and accessory muscles of inhalation and exhalation are listed in Table 1. The diaphragm is the primary muscle responsible for providing 70-80% of the inhalation force and is composed of the skeletal/costal and crural portions. The diaphragm is evaluated from the perspective of vital functions such as breathing and metabolism. Postural, visceral, and sphincter functions are important components that are often forgotten roles of the diaphragm.

A normal breath at rest is referred to as a belly, diaphragmatic, or abdominal breath. Upon inhalation the diaphragm should move caudally toward the pelvic floor with symmetry, while flattening and compressing the internal organs; the lower ribcage should move proportionately and symmetrically in a lateral, ventral and dorsal direction. The abdominal
walls should all expand equally in a cylindrical manner. The sternum moves ventrally while the intercostal spaces between the ribs expand minimally at the end of inhalation.3

**ASSESSMENT OF BREATHING PATTERNS**
The assessment of the patient’s breathing pattern begins when the patient enters the clinic. During that time the patient is unaware that they are being observed, which reduces the possibility of conscious changes to breathing patterns.6 The patient's posture should also be observed, as a slumped or hunched posture can limit the ability of the diaphragm to fully expand.18 After the initial observational breathing pattern assessment and a full patient history, the clinician can start a comprehensive breathing examination.

Breathing is commonly assessed in a relaxed, supine position, but can also be observed in more challenging positions such as sitting, standing, or in positions that result in pain or discomfort.6 During the Hi Lo assessment the patient is directed to place one hand on their chest, while the other hand rests on their abdomen (Figure 1). Once in this position the patient is not given any further instructions but the clinician may ask him or her questions regarding their history. The patient should breathe normally, and not be cued to take a deep breath during the assessment, as typically a prompted breath will result in the movement of the chest unless the patient has had previous training in abdominal breathing.6

The assessment of breathing patterns is most often marked by the practitioner's observations, however standardized techniques are necessary to quantify a diagnosis. The Manual Assessment of Respiratory Motion (MARM) is a palpatory method that quantifies breathing patterns in a practical, inexpensive, and

<table>
<thead>
<tr>
<th>Table 1. The Primary and Accessory Muscles in Inhalation and Exhalation</th>
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<tbody>
<tr>
<td><strong>Muscles of Inhalation</strong></td>
</tr>
<tr>
<td><strong>Primary</strong></td>
</tr>
<tr>
<td>Diaphragm</td>
</tr>
<tr>
<td>Parasternal internal intercostals</td>
</tr>
<tr>
<td>Upper and lateral external intercostals</td>
</tr>
<tr>
<td>Levatores costarum</td>
</tr>
<tr>
<td>Scalenus (less active during normal breathing)</td>
</tr>
<tr>
<td><strong>Accessory</strong></td>
</tr>
<tr>
<td>Sternocleidomastoid</td>
</tr>
<tr>
<td>Upper trapezius</td>
</tr>
<tr>
<td>Serratus anterior</td>
</tr>
<tr>
<td>Latissimus dorsi</td>
</tr>
<tr>
<td>Iliocostalis thoracis</td>
</tr>
<tr>
<td>Subclavius</td>
</tr>
<tr>
<td>Omohyoid</td>
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Listed above is a comprehensive list of the primary and accessory muscles that are associated with proper breathing patterns. When there is a BPD the accessory muscles replace the primary movers.3

* Primary non-muscular anatomic structures associated with breathing.
Clinicians have used the MARM to assess diaphragm function since the 1980s to determine thoracic, abdominal and lateral breath. The MARM has good inter-examiner reliability (ICC = 0.85, p = .0001, CI 0.78, 0.89) as compared to plethysmography. The MARM is performed by having the clinician positioned behind the seated patient and placing their hands on the posterior and lateral aspects of the 11th and 12th ribs. While the patient breathes, the clinician measures perceived displacement and functional movement of the upper and lower rib cage movement, as well as abdominal expansion using two lines drawn on the patient to form a half of a pie chart and pressure placed through the clinician's hands (Figure 2). The MARM values are calculated by measuring angle differences between the highest point of the inhalation (upper rib cage) and the lowest point (lower rib cage). Each side of the body is considered its own entity and measurements should be between zero and 180 degrees. Positive values are indicative of chest breathing/vertical movement and negative values indicate abdominal/lateral movement.

Patients are assessed for tender areas, jump signs, or withdrawal reflexes upon palpation at the 1st/2nd, 7th/8th, or 11th/12th ribs unilaterally or bilaterally, as this may be a sign of faulty breathing patterns. John Iams proposed that patients displaying increased sensitivity to normal palpation have an autonomic nervous system (ANS) that may be unable to balance the body's involuntary systems (i.e., parasympathetic and sympathetic nervous systems). Theoretically, if the patient's body is functioning mainly in a protective state through activity of the sympathetic nervous system (SNS), a state of “up-regulation” may exist that presents as a startle or withdrawal reflex upon palpation. If a patient presents with a startle reflex, or sensitivity to one or more of these locations, manual therapy could be used to “down-regulate” the area(s) or inhibit the pain cycle. Therefore, assessing these specific locations with palpation may be important in clinical practice, as an “up-regulated” ANS could be a source of BPDs and musculoskeletal pain.

CLASSIFICATION OF BREATHING PATTERN DISORDERS

There are many possible variations of classifications of BPDs, however, six primary dysfunctions found in the literature have become the foundation of the BPD assessment. A normal breathing pattern is classified as diaphragmatic or abdominal breathing. Although this is considered a normal breathing pattern, it should be noted that a “normal” breathing pattern found in patients should not be considered the ideal functional breathing pattern. A few dysfunctional variations of an abdominal breath exist, including: asymmetrical with limited motion on one side of the abdomen; anterior movement only, without lateral or posterior movement; and adequate anterior and lateral movement, without posterior.

A chest or apical breather is characterized by excessive movement of the sternum and shoulder girdles toward the cranium, and minimal abdominal movement during inhalation. Paradoxical breathing is when the chest expands during inhalation and the abdomen is drawn inwards and then during exhalation the abdomen is pushed outwards. A new BPD classification, proposed by the authors of this commentary, is associated with a startle reflex. A startle reflex is when a patient elicits a withdrawal reflex upon palpation to the right or left 1st and 2nd ribs, anterior 7th and 8th ribs, and 11th and 12th ribs. In part 2 of this series, three patient cases will be presented that display the short-term effects of treating a startle reflex BPD. Figure 3 is a visual representation of the classification of BPD in a rehabilitation clinic.

OUTCOME MEASURES

Breathing pattern assessments, patient reported outcome measures, and other examination findings help to build a complete picture of BPDs.
measures identify minimal clinically important differences in patients with pain and dysfunction to determine the effectiveness of a clinician’s assessment and treatment. A number of outcome measures can be used to quantify efficacy of evaluations and interventions in decreasing pain and correcting dysfunction in patients. Measurement tools to evaluate musculoskeletal pain and/or dysfunction include the Numerical Pain Rating Scale and the Disablement in the Physically Active scale. The Nijmegen Questionnaire is a patient-reported outcome measure used to identify the presence of signs and symptoms associated with general and respiratory distress and higher values represent distress and dysfunction of the respiratory system. These tools can easily be incorporated into an orthopedic examination without the addition of too much time. Outcome measures should encompass both clinician and patient-reported evidence. Clinician-reported measures that may be useful in the collection of outcomes are the findings from the physical examination (functional impairments, range of motion, strength, asymmetry, MARM, Hi Lo, etc.). Patient-reported measures that may be useful in the collection of outcomes are the Numerical Pain Rating Scale, Disablement in the Physically Active scale, and Nijmegen Questionnaire, as well as specific patient-oriented evidence measures that can be used at the clinician’s discretion.

All outcome measures can be used in conjunction with comprehensive examination and functional biomechanical assessment (e.g. Selective Functional Movement Assessment). The CNS allows for optimal positioning of posture and stability through functional movement patterns. Through the use of a functional assessment, the clinician may be able to locate pattern deficiencies contributing to the chief complaint(s) or less than optimal movement patterns. The correction of breathing patterns in low level postures should occur first and be followed by integration of proper breathing into complex movement patterns.

**CLINICAL ADVANTAGES**

Breathing is an involuntary process thought to be an essential aspect of posture and core stability. Restoring proper breathing mechanics and motor control can result in decreased pain, improved patient outcomes, and improved patient health. Evaluation of breathing patterns is an easy clinical technique to learn. Treating BPDs requires little to no equipment in the rehabilitation clinic and intervention techniques provided by the clinician can be structured as a home exercise program in approximately five minutes or less.

**DISCUSSION**

The purpose of this clinical commentary was to illustrate how to assess and classify BPDs prior to or in conjunction with the treatment of musculoskeletal pain or dysfunction. Since a BPD is not a disease, it is usually not recognized until an assessment is performed. The specific cause(s) of BPDs are unknown, and each patient may adapt individual neuromuscular patterns associated with faulty breathing patterns. Postural and structural adaptations could possibly result in pain and/or dysfunction of muscles, ligaments, or joints with no apparent organic source, possibly resulting in various BPD signs and symptoms. The three main contributing factors to BPDs are: biomechanical, biochemical, and psychological.

The act of breathing is mechanical in nature as the diaphragm and primary muscles control most of the respiratory system. Restriction of muscle length, muscle imbalances, and diaphragm expansion can modify posture and core stability as a result of the body’s inability to return to optimal resting position. The concept of regional interdependence suggests that if one part of the kinetic chain is unable to perform motor patterns sufficiently, another portion of the body compensates for the deficiency,
resulting in dysfunction. Breathing patterns may change as a result of altered motor control patterns and postural changes and if the imbalances are not addressed can lead to suboptimal function of the CNS and chronic pain. While the biomechanical factors are visible to the clinician it is important to remember biochemical components of the respiratory system as well. Changes in the body’s pH level, allergies, dietary factors, hormone levels, or internal organ dysfunction can potentially lead to premature fatigue, breathlessness, dyspnea, and resultant muscle pain. The mind and body work together to maintain homeostasis during times of stress and anxiety. While research is limited in understanding the emotional factors contributing to BPDs, researchers have suggested that memories, past experiences, and emotional states can have an effect on breathing patterns.

“If breathing is not normalized, no other movement pattern can be.” Frank et al and Chaitow suggest that abnormal stabilization patterns are associated with BPDs and should be the starting point for all orthopedic evaluations. The authors believe that correction or re-education of BPDs can result in new neural connections and restoration of normal motor control patterns in the CNS. Roussel et al observed various dysfunctional breathing patterns and altered motor control patterns during functional testing in a group of patients with low back pain compared to a group of healthy individuals. Breathing patterns are established subcortically and often associated with an injury, pain, and/or movement dysfunction. The goal of restoring breathing patterns is to establish normal subcortical motor patterns. An athlete with an abnormal breathing pattern during physical activity may experience premature breathlessness or muscle fatigue, resulting in decreased performance.

**CONCLUSIONS**

The assessment and classification of BPDs is important, as normal and abnormal breathing patterns affect movement. Once a breathing dysfunction is classified, finding appropriate exercises for muscle relaxation, re-education of motor control patterns, and normal breathing patterns at rest and during activities may help restore normal and physiological balanced breathing. Breathing pattern assessments and interventions might improve patient quality of life, physical function, and decreased breathing signs and symptoms during activities of daily living and exercise. Part II of this clinical commentary will provide a case series related to BPDs in an athletic population, the interventions associated with BPDs, and the effects of BPDs interventions.

**REFERENCES**


Abstract

Background: Dry needling (DN) is an evidence-based treatment technique that is accepted and used by physical therapists in the United States. This clinical commentary is the second in a two-part series outlining some of the pertinent anatomy and other issues that are needed for optimal utilization of this treatment modality. Part one was an overview of the thorax with a summary of reported adverse effects (AEs) and the underlying anatomy that could be used to minimize patient risk. As is the case with any intervention, the technique of dry needling has some inherent patient risk. The incidence of AEs with this procedure is typically low, ranging from zero to approximately 10 percent. Knowledge of the underlying anatomy can be a key factor associated with decreasing the likelihood of an AE.

Purpose/Objective: The second part of this clinical commentary goes beyond the thorax, to explore the anatomy associated with dry needling the abdomen, pelvis, and back. In the abdomen, pelvis and back, dry needling can penetrate the peritoneal cavity or adjacent organs, resulting in AEs. A physiological reaction that is an AE secondary to a needle insertion, pain or fear, is an autonomic vasovagal response. Additionally, suggestions for dealing with the fearful patient, the obese patient, universal precautions, and other clinical considerations, are discussed. The purpose of parts one and part two of this clinical commentary is to minimize the risk of a dry needling AE.

Conclusions/Implications: Dry needling is an effective adjunctive treatment procedure that is within the recognized scope of practice of the physical therapist. An evidence-based implementation of the procedure must be based on a thorough understanding of the underlying anatomy and the potential risks, with risks communicated to patients via informed consent.

Level of Evidence: Level 5

Keywords: Adverse effect, anatomy, dry needling, informed consent, pneumothorax, vasovagal response
INTRODUCTION
A common anatomical phrase used during gross anatomy instruction is that ‘structure sub-serves function’. Succinctly stated, the key meaning of this statement is that the structural design of the sub-units that make up the human body underlies the function of these sub-units, and understanding this design provides the clinician with ways to test and safely intervene in the presence of dysfunction. As was outlined in part one of this clinical commentary,1 the underlying anatomy across individuals has variability, and an in-depth knowledge of anatomy is required prior to DN or any other type of needle placement (acupuncture, EMG, etc). Part one1 dealt with the thorax and issues that can be associated with small diameter needle placement in this region such as pneumothorax, cardiac tamponade, hematoma, central nervous system injury, and other complications. In addition, the first clinical commentary provided a description of DN, the theories associated with its use, how physical therapists are well positioned to perform this procedure effectively and safely due to their professional training, and the variable frequency of AEs reported in the literature. This second part of the clinical commentary will examine some potential issues associated with placing a needle in or near the abdomen, pelvis, back, or other areas such as the extremities. In addition to direct structural considerations, other general responses that can occur during dry needling such as a vasovagal response are described and considered. Lastly, the issue of providing informed consent for dry needling will be addressed with several suggestions outlined, as well as a discussion of the fearful patient, the obese patient, universal precautions, and DN as an adjunctive procedure.

Dry Needling In the Region of Abdomen, Pelvis and Back
The abdomen and pelvis constitute the region below the diaphragm extending inferiorly to the perineal region. Unlike the separation of the thorax from the abdomen by the musculotendinous structure of the diaphragm, there is not a clear boundary that separates the abdomen and pelvis.2 Rather, for descriptive purposes the abdomen is considered as that region inferior to the diaphragm that remains superior to an imaginary line running from L5-S1 to the pubic symphysis.2 The pelvis is that region below the previously cited imaginary line, inferiorly represented by the perineum with the pelvic diaphragm (levator ani muscles).2 Like the thorax that has a pleural cavity that encompasses the lungs, the combined abdomen and pelvis have many structures enclosed within the peritoneal cavity. The peritoneal cavity is lined by a surface that consists of parietal peritoneum in proximity to the endoabdominal fascia, and visceral peritoneum that is adjacent to the structure that is enclosed or covered. Functionally, this provides a closed space within the peritoneal cavity, with the one exception in females of a small open pathway associated with the ovaries and the fimbria of the fallopian tubes.2 The enclosed region encases or covers key structures such as the stomach, duodenum, spleen, pancreas, and large and small intestines, as an abbreviated list. Structures that pass from the abdomen and pelvis into the lower extremity are typically retroperitoneal, existing behind the posterior extent of the peritoneal cavity.2 Some of the structures that are contiguous to the peritoneal cavity, either passing into the lower extremity or existing behind the peritoneal cavity, are at potential risk when dry needling in this region is performed. The next several paragraphs highlight dry needling sites in the region of the abdomen and pelvis that have the potential for AEs and factors that should be considered by the clinician employing this technique in these regions. By and large, this involves a clear understanding of the regional anatomy and what tissues the needle passes through to reach its intended target.

Needling the iliacus superior to the inguinal ligament: One site that is described as a DN site is the iliacus.3 When a clinician determines that this muscle should be needled due to either a clinical condition associated with this muscle or trigger points identified as arising within the muscle, then a determination needs to be made on whether the site of the needle placement should be superior to or inferior to the inguinal ligament. This muscle is commonly needled to treat conditions like pelvic floor pain, hip flexor strain, or iliobibial band tendinitis.4–6 For review, the iliacus muscle runs from the upper two-thirds of the iliac fossa, the ala of the sacrum, and the anterior sacroiliac ligaments, passing under the inguinal ligament to insert on the lesser trochanter of the femur.2 The inguinal ligament runs...
from the anterior superior iliac spine (ASIS) to the pubic tubercle, and is more appropriately the turned under connective tissue fibers of the aponeurosis of the external abdominal oblique muscle, rather than a typical ligament that runs from bone to bone. As such, the iliacus resides in the posterior abdominal wall and in the proximal aspect of the thigh, each of which have some specific anatomic challenges to safe needle placement. Should the decision be made to place a needle in the bulk of the muscle superior to the inguinal ligament, then the clinician will be passing through the following layers of the anterolateral abdominal wall to move deeply toward the level of the muscle (protected posteriorly by the bony ilium). The needle will pass through the following: (1) the skin; (2) Camper’s and Scarpa’s fascia (Scarpa’s fascia is a specialized deep membranous layer within the lower abdomen comprised of elastic and collagen fibers, providing sufficient strength that surgeons may include this layer when suturing); (3) three thin muscle layers with their surrounding deep investing fascia or their respective aponeurosis (in the case of the anterior-lateral abdominal wall muscles, they are the external abdominal oblique, internal abdominal oblique, and transversus abdominis); (4) transversalis fascia; (5) a thin layer of extraperitoneal fat; and (6) parietal peritoneum. Once the peritoneal cavity has been entered, it is likely that the needle will also pass through visceral peritoneum, and some of the tissue structures that occupy this space (such as the descending or sigmoid colon), will be impacted when needling on the left side of an individual. Anecdotal reports are that some instructors teach that the colon or aspects of the intestines can be mobilized and moved off of the iliacus muscle, but the anatomical layout of this region of the abdomen and pelvis argues against such a possibility. Structurally, it is not advantageous for the contents of the abdomen to be freely moveable, since this could lead to a twisted gastrointestinal tract (a twisted loop of bowel is a volvulus and while possible, is more likely to occur in other animal species such as quadrupeds). The small intestine is firmly affixed posteriorly by the mesentery to the posterior abdominal wall and serves as a pathway for the blood vessels and nerves that supply the abdomen, with the anterior aspect of the small intestines being more mobile. In terms of the large intestines, on the right side the ascending colon is described as being ‘secondarily retroperitoneal’, as is the descending colon on the left side. What this means is that while the ascending and descending colons were developmentally intraperitoneal and relatively mobile, as they formed they ‘fell-back’ onto the posterior abdominal wall and became affixed to the posterior abdominal wall. So, structurally, at the time of surgery or upon opening the abdomen in a cadaver lab, these structures are fixed in place along the two sides of the abdomen and are therefore not moveable by the clinician attempting to push them out of the way to insert a needle. When a needle is placed in this region, it will, by necessity, pass into and puncture the peritoneal cavity and the needle has the potential to pass into a portion of the bowel.

Due to the location of the colon, another safety procedure that has been advocated when dry needling in this region is to use a needle only once and discard it to minimize issues should the intestines be penetrated. If a needle has potentially perforated a bowel, albeit with a very small diameter needle, contamination could occur that would involve the peritoneal cavity. Should a real infection develop, this would be a peritonitis. While this type of infection associated with needling has not been reported in the literature, the structural possibility should be considered, and any clinician performing dry needling in this region should consider both the potential risk and the inherent benefit of needling here.

Needling the iliacus inferior to the inguinal ligament: The distal aspect of the iliacus muscle, just before it inserts into the lesser trochanter of the femur, constitutes the floor of the lateral aspect of the femoral triangle (the femoral triangle is a region demarcated by the sartorius laterally, the adductor longus medially, and the inguinal ligament superiorly). Should the decision be made to needle the distal portion of the iliacus due to its relationship to the pelvic floor, the muscle can be needled while avoiding the peritoneal cavity. This can be done with relative safety since the anatomy in this region is predictable, with the key structures overlying this muscle represented by the acronym N A V E L (nerve, artery, vein, empty space, and lymph tissue, when proceeding from lateral to medial). If a clinician is able to palpate the femoral artery and then move laterally a couple of centime-
ters while staying medial to the sartorius muscle, they should be able to place the needle into the combined iliacus and psoas major muscle (iliopsoas). Properly positioned, the key structures of the femoral nerve and femoral artery should be avoided. The emphasis is on ‘should’, since there are at least two variants in this region that can complicate the issue, the structure of the femoral nerve and the variability in branches arising off of the femoral artery. The femoral nerve differs from most other peripheral nerves in the body, since after passing under the inguinal ligament, it splits into multiple (many) fascicles that spread out to supply both cutaneous and muscular branches. This extensive splitting is recognized with some functional tests such as nerve conduction velocity assessments, where it has been noted that “there is no reliable method of measuring the motor NCV (nerve conduction velocity) in the femoral nerve” .9 Following palpation of the femoral artery, the clinician can move laterally in the femoral triangle and work to avoid the nerve. This will typically be effective, but due to the presence of many fascicles, it is possible to place the needle in a fascicle that is more laterally positioned than what is normally described in anatomy texts.2,10 Second, arteries have more variability than nerves2 and do not always follow the classical course described in anatomy texts. One of the authors has referenced a variant where a large lateral circumflex artery arose directly off the proximal femoral artery and passed superficially in a lateral and circumscribed course described in anatomy texts. This arterial variant can complicate the issue, the structure of the femoral nerve and the variability in branches arising off of the femoral artery. The femoral nerve differs from most other peripheral nerves in the body, since after passing under the inguinal ligament, it splits into multiple (many) fascicles that spread out to supply both cutaneous and muscular branches. This extensive splitting is recognized with some functional tests such as nerve conduction velocity assessments, where it has been noted that “there is no reliable method of measuring the motor NCV (nerve conduction velocity) in the femoral nerve” .9 Following palpation of the femoral artery, the clinician can move laterally in the femoral triangle and work to avoid the nerve. This will typically be effective, but due to the presence of many fascicles, it is possible to place the needle in a fascicle that is more laterally positioned than what is normally described in anatomy texts.2,10 Second, arteries have more variability than nerves2 and do not always follow the classical course described in anatomy texts. One of the authors has referenced a variant where a large lateral circumflex artery arose directly off the proximal femoral artery and passed superficially in a lateral and distal direction across the femoral triangle.11 Had this individual been needled in a manner that was completely appropriate according to an atlas, but without an awareness of arterial variability, the noted arterial variant could have become compromised. Since this anatomical variant was superficial, a needle placed in the substance of the artery may have resulted in a significant hematoma. The only way to absolutely assure that this would not happen would be to use a modality like diagnostic ultrasound, to visually inspect the region prior to placing a needle into the distal aspect of this muscle. On occasion, hematomas will occur as AEs, and these are typically minor adverse effects. While the patient should have been informed before the procedure that this type of outcome could occur, due to the needle size, this typically is not a major event that would change or prohibit the utilization of the needle insertion in this region.

The quadratus lumborum: The quadratus lumborum is also known as the ‘hip-hiker’ muscle. This muscle is a deep muscle in the back, and it is occasionally the target for dry needling.12 Simons and Travell suggest that this muscle can refer pain to regions like the lateral thigh, sacroiliac region, lower gluteal region, along the iliac crest, to the lower abdomen, and to the inguinal region.13 Due to this potential distribution of referred pain and symptoms, needling of this muscle may be implicated for lateral thigh pain, inguinal pain, and pain in the region of the sacroiliac joint. This muscle arises from the medial half of the inferior border of the twelfth rib and tips of the lumbar transverse processes, and extends inferiorly to the iliac crest and iliolumbar ligament.2 In terms of its accessibility by a needle, this structure has an advantage over the iliacus in that the muscle is both retroperitoneal (behind the peritoneum), and accessible from a posterior approach. So, a needle can be placed within the muscle without entering the peritoneal cavity. Having noted that, there are a number of other anatomical structures that may be implicated or involved with a needle insertion in this region. The first is a kidney, a retroperitoneal structure typically located towards the lateral portion of the quadratus lumborum muscle. However, it should be noted that anatomy atlases show the typical two kidney configuration, and kidneys vary widely in shape and size, with variants such as the ‘horseshoe kidney’ that is continuous across the midline. This variant is the most common type of renal fusion anomaly.14 A needle placed in this region has the potential to enter a kidney, unless the clinician is able to be certain of the depth of penetration, through the use of imaging ultrasound or some other imaging modality. Other structures that are in the region and are also susceptible to being penetrated by a needle are the sympathetic chain, the suprarenal glands, renal arteries and veins, the ureter, and the posterior aspect of the iliohypogastric and ilioinguinal nerves.2 The key point here is that the quadratus lumborum muscle is a deep structure and the clinician placing a needle in this muscle needs to be familiar with the pertinent anatomy and inherent risks associated with placing a needle in this structure.

Other structures: There are clearly many other structures that can be and are needled, such as the lumbar paraspinals, muscles associated with the tempo-
mandibular joint (TMJ), and very deep regions such as the suboccipital muscles at the base of the skull. In an effort to keep this overview relatively concise, those regions such as the lumbar paraspinals that have minimal risk associated with a needle insertion are not discussed here. Additionally, those muscles that take specialized or advanced knowledge to accurately place a needle, such as the lateral pterygoids that insert into the capsule of the TMJ are not elaborated upon because the advanced instruction given on needling this muscle should make the clinician well aware of the large parotid gland, extensive venous plexus, maxillary artery arising from the external carotid artery, and nerves in the area, including the mandibular nerve, lingual nerve, inferior alveolar nerve, and chorda tympani nerve. The lateral pterygoid may be needled due to pain referred to the maxilla and/or the TMJ, and for the clinical indications of headache and TMJ dysfunction. This is also the case for the deeply situated sub-occipital muscles at the base of the skull, that have both the vertebral artery located in the base of the sub-occipital triangle, as well as the suboccipital nerve and the greater occipital nerve just inferior to this area. The suboccipitals may be needlel due to deep pain that spreads from the occiput toward the orbital region, and are used clinically for things like tension headache and neck pain. Since these are recognized as specialized regions, the clinician treating such areas should have the requisite training and experience to safely provide expert care.

The above examples of both commonly needled sites and the brief mention of more specialized regions illustrate that a firm understanding of the structure and function of a given region is imperative for safe clinical care. While the intent of most of the anatomic descriptions within both part one and part two of the clinical commentary has been to identify other structures where it would not be ideal to place a needle, it should also be stressed that DN is not restricted to muscle target sites with ‘trigger points’ as the only point of interest. Dunning, in his 2014 article summarized this well when he noted that in addition to muscular trigger points, other target structures included ligaments, scar tissue, tendons, bone, and connective tissue, all of which are types of connective tissue. In addition, ‘a high density of neurovascular structures’ has been found at dry needling sites. Vasovagal response: The previous examples of the possible interaction of a needle with the underlying anatomy have all been described as the direct result of the needle placement. Another potential response indirectly related to use of the needle or another stimulus that can result in an autonomic response is known as a vasovagal response. Any type of stimulus, including but not limited to visually seeing something that causes fear, visualizing blood, and experiencing pain, have the potential to result in an increased parasympathetic response that can cause the individual to become lightheaded, with the response potentially progressing to a loss of consciousness. A vasovagal response is also known as neurally mediated syncope. Basically, the body has a superb mechanism that maintains blood pressure in spite of a variety of body positions and other challenges that occur throughout the day. Take the case of moving from a sitting position to a standing position. Blood has a tendency to pool in an individual’s lower extremities, and it is possible for this change in posture to result in a “relatively empty ventricle owing to shifting of blood from the thorax to the abdomen and lower extremities.” This type of a change in position can reduce the cardiac output and decrease the amount of blood that is available to the brain. However, normally within a beat of the heart, the decreased output is identified by the arterial baroreceptors located in the carotid sinus and aortic arch. These receptors transmit signals via the sympathetic trunk to increase sympathetic output. The sympathetic output also results in vasoconstriction to non-vital organs and the extremities, along with an increase in heart rate, both of which work to maintain adequate blood flow to the brain. In a vasovagal response, the stimulus created by fear, a needle, or some other stimulus, results in the parasympathetic portion of the autonomic nervous system responding to this stimulus by sending an efferent response that results in bradycardia, hypotension, and syncope. The individual undergoing this type of reaction from the abridged list of stimuli outlined above or some other stimulus, may describe symptoms such as lightheadedness, sweating, and potentially have a loss of consciousness.

The common element is some type of trigger, that may cause the patient to have an altered sense of temperature (often feel either hot or cold, typically accompanied by sweating), confusion, tinnitus, and
a feeling of nervousness and/or an uncomfortable feeling in the chest.¹⁹ In one of the author's experience,²² small gauge needle placement in the upper thoracic region, especially when the subject is sitting upright rather than lying prone, can result in this type of response. A research study by Lagasse et al²² investigating a nerve conduction technique for the supraspinatus, bilaterally. In the series of 45 subjects, four of the subjects (9%) developed a sensation of being light headed and required removal of the needle and the opportunity to lie down. The sitting position may have influenced the incidence observed during this study. This is based on the anecdotal observation by one of the author's that when performing electromyography studies with the patient prone at the time of the needle insertion, the incidence is near zero.

Should a vasovagal response occur, and it will occur for many practitioners performing dry needling over a period of time, key factors are to both provide a safe environment for the individual to not over-react. Positioning patients appropriately prior to needling provides a safe environment, ensuring that if an individual becomes light headed or loses consciousness, they will not fall to the floor or move in any way that would create a potentially harmful situation. One of the authors has described this approach of utilizing positioning, safety, and not over-reacting as being 'laid back' when a vasovagal response occurs. This phrase of 'laid back' is intended to assist the clinician to recall that it will be beneficial for the patient to lie down, so that blood flow in the extremities is at the same level as the heart. The feet can be propped-up, to additionally assist with blood flow. The phrase also suggests that the clinician performing dry needling should be in a position to deal with the vasovagal response in stride, without unduly alarming the subject. In most cases, this will be minor and transient, and typically will not involve much more than stopping the treatment and dealing with the patient's needs.²¹,²³ In the relatively rare case where an individual loses consciousness, insure that the head is turned to the side to facilitate breathing, and closely monitor the subject. It may also be appropriate to loosen their clothing, to ensure that there is not a restrictive stimulus from the clothing. If consciousness has been lost, then in addition to monitoring the subject and potentially activating the emergency medical response system, there may be a need to have them fully evaluated by an appropriate health care practitioner, especially if they have fallen or if there has been any other associated event. At a minimum, this is an ‘unusual occurrence’ and should be treated as such through the policies in place at the facility where dry needling is utilized. Additionally, there should also ideally be some follow-up later that day to insure that the subject has fully recovered and is doing well. Vasovagal responses are not rare, they will occur, but the therapist involved should have a clear plan of action in place and not over-react.

Other important considerations associated with minimizing potential adverse effects

**Informed consent:** Dry needling is an invasive procedure that is within the scope of practice of physical therapists, physicians, and other health care providers approved by their state licensing boards. Since this is an invasive procedure, the patient should be informed about inherent risks in the form of informed consent. As was noted in the Witt et al self-report survey of almost 230,000 patients, 8.6 percent reported an adverse effect that was noteworthy and 2.2 percent reported an adverse effect that required treatment.²⁴ In most cases when there is an adverse effect, it will be minor such as a notable bruise, small amount of bleeding, muscle soreness, or transient light-headedness. Since this procedure is invasive and has a potential for an untoward effect, the patient should be informed of the small inherent risk. Written consent is appropriate since it meets the standard of providing “explicit and specific consent is deemed necessary for invasive procedures”.²⁵ Through informed consent there is a mechanism for protecting the legal rights of patients and insuring that they are involved in the decision making regarding their care.²⁶ This dates back to 1914, when the legal precedent for ‘simple’ informed consent was devised that established a patient’s “right to determine what shall be done with his [her] body”.²⁶ This was expanded in 1975, with clarification of a reasonable person standard that requires the practitioner to disclose the information that a “reasonable person” would want to know in a similar situation.²⁶

There are potential problems with informed consent that a clinician has to consider. First, if the procedure is typical and customary, it is essential that informed
consent beyond ‘implied consent’ is required? This is an area that has not been as explicitly defined as has been done in research where informed consent is codified for any research with minimal risk. As Wada et al point out, “circumstances seem to exist which allow clinicians to proceed with certain clinical procedures with implicit consent, suggesting that conditions for not requiring formal consent or risk disclosure may exist”. As is stated above, this procedure probably does not fall into that category since the procedure is invasive and there is a clear history of some AEs associated with dry needling procedures. Second, providing an informed consent and answering patient’s questions takes time. In one study that dealt with more invasive procedures than is encountered when performing DN, the mean time taken by providers for elective surgery procedures was 10.9 minutes, with a large standard deviation of 22 minutes. Third, the patient could perceive that something unusual is being done since many of the procedures that are performed by physical therapists do not entail the extra step of informed consent, apart from any paperwork processing that is typically filled out at the time of the first visit or verbally explaining the procedure. This concern is probably balanced by the advantage of including the patient in the decision making process and by being able to clearly articulate the minimal risk in light of the potential benefit to the patient. Additionally, if needling an area that has more than minimal risk, such as in and around the thorax, having an informed patient that understands that not all untoward effects necessarily occur at the time of the treatment is an advantage. It is well documented that when something like a pneumothorax occurs, it may occur at the time or as long as three days after the treatment. An informed patient is able to then respond appropriately, maximizing the chance for a positive outcome even in the case of an AE.

Should the clinician agree that informed consent is the right standard of practice to employ with this clinical procedure, then the guidelines identified by Hall et al in their article “Informed consent for clinical treatment” might be helpful. The suggested framework that they describe includes: “(1) develop a practice of involving patients in decisions; (2) explicitly establish the goals of care, and prioritize them in the context of the patient’s other life goals; (3) recognize that the informed consent process serves more than one purpose (legal, ethical, administrative, and the development of patient trust); and (4) document the process thoroughly, using an electronic medical record whenever possible to ensure permanence.”

Other patient considerations

The fearful patient: Dry needling is one therapeutic procedure that a clinician has at their disposal to treat specific neuromusculoskeletal conditions. The exact mechanism associated with the demonstrated efficacy is not yet known, and it is probable that there are benefits simply from the personal interaction and the physical procedures employed. If the patient is overly concerned about being treated with a needle, secondary to pain or some other concern, it is likely that the outcome will not be optimal. There is the additional concern of a vasovagal response, since simply being fearful can be enough to elicit this type of response. In the case where an individual is unduly concerned about the treatment suggested by the clinician, this is an instance where another form of treatment may be the best approach.

The obese patient: Dry needling is generally thought to entail an interaction between a muscle trigger point and the needle. To accomplish this successfully, the clinician needs to be able to identify the trigger point and be confident that the needle is being placed in the intended structure or muscle. In an individual that is significantly overweight or obese, this becomes problematic due to the thickness of the superficial fascia (fat) that has to be traversed to reach a therapeutic level. The real issue is not the superficial fascia per se, since a needle of the appropriate length can be obtained that will reach the desired depth. The concern is that the intervening tissue makes precise localization of the needle more difficult. If needling is performed in a region such as an extremity or the lumbar multifidus muscles, this can be done in most cases with a high degree of safety since should the needle not be in the precise expected location, the sites are ones where there is some latitude regarding the needles placement. However, when dealing with sites involving the thorax, abdomen, or sites where there could potentially be an aberrant large artery or other structure, the increased superficial fascia mass creates a safety issue. In these cases, the clinician
needs to consider the risk versus the benefit for the patient and make a judgment call. If the procedure can be done safely and the clinician believes that they are able to determine the location and depth of the needle placement, then dry needling may be an appropriate intervention. In those cases where there is a higher risk of an AE, it may be that there is a better therapeutic intervention for that patient. The American Physical Therapy Association’s educational resource paper entitled ‘Description of Dry Needling in Clinical Practice’, outlines 15 precautions, in addition to obesity, to be aware of in prospective patients, to include (abridged list) patients with a cognitive impairment, those unable to communicate, local skin lesions, patient’s allergic to the metal in the typical needle, those with a compromised immune system, following some surgeries, and pregnancy.33

Dry needling and the use of universal precautions: Any endeavor that involves a needle has the potential for bleeding, albeit small with most dry needling procedures. Universal precautions were clearly outlined in the Federal Register as early as 1991,34 in order to minimize occupational exposure to a number of pathogens that can be spread by contact with blood or other bodily fluids. It is undisputable that when exposed to blood, there is a risk of transmission of Hepatitis B Virus (HBV), Hepatitis C Virus (HCV) and human immunodeficiency virus (HIV).34,35,36 This argues for the use of gloves for the protection of the health care worker involved with dry needling. While this does not appear to be an area where there would be any controversy, a brief perusal of the Internet found both a dry needling site,37 and an acupuncture site,38 where the clinician demonstrating needle placement did so with bare hands. Universal precautions should be employed for the protection of the clinician performing dry needling, as well as reinforcing for all involved that for the patient, the needle also needs to be sterile. While not directly related to universal precautions, there is at least one case study referencing the infection of a hip prosthesis after dry needling.39 Although causality cannot be determined from a case study such as this and it is recognized that DN may not have been the cause of this individual’s infection, the skin is being penetrated with DN and therefore systematic, reasonable steps should be utilized for the protection of both the patient and the practitioner.

Dry needling is typically an adjunctive treatment: While dry needling has been demonstrated to be an effective therapeutic approach to a broad variety of neuromusculoskeletal complaints, rarely should it be considered a ‘stand-alone’ procedure. Since dry needling has been shown to treat a variety of dysfunctions in muscle, fascia, connective tissue, and decrease persistent pain, it can be tempting to consider this as a modality or treatment approach that would benefit a significant portion of a patient population that is seeking care for neuromusculoskeletal problems.33 With each presenting patient there is an underlying cause of their issue and the patient history, physical exam and other specialized tests should be performed to permit an understanding of the etiology of their symptoms. The treatment provided should then be designed to address or eliminate the etiology of their problem, and this will not usually be achieved with dry needling alone. As effective a modality as dry needling may be, it is typically adjunctive to some other focused treatment approach.40

CONCLUSION
Dry needling is an evidence based treatment modality that has broad application in the treatment of numerous neuromusculoskeletal complaints, when applied by a skilled and knowledgeable professional. The approach focuses on releasing or inactivating muscular trigger points to decrease pain, reduce muscle tension, and assist patients with accelerated return to active rehabilitation. To be performed effectively and safely, minimizing the chance that an AE might occur, the clinician must have a clear understanding of the underlying anatomy of the region being dry needled. This clinical commentary, along with a preceding clinical commentary that discussed issues associated with the thorax,1 have outlined areas of potential concern associated with the neck, thorax, abdomen and pelvis, and discussed relevant anatomy in those areas. Other conditions such as the potential for a vasovagal response, dealing with the fearful or obese patient, and the role for informed consent with dry needling were also reviewed. Future research might examine educational and evaluative techniques to provide feedback on needle placement, a systematic way to collect data on AE’s and identify methods to reduce their incidence, and
the impact of factors such as body position on the incidence of vasovagal responses. Recognizing the need for a thorough understanding of anatomy and a systematic approach with the application of dry needling should help to minimize the incidence of AE’s and increase the positive results obtained with this therapeutic technique.

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