ABSTRACT

Purpose: The purpose of this systematic review was to determine the exercises that optimize muscle ratios of the periscapular musculature for scapular stability and isolated strengthening.

Methods: A systematic search was performed in PubMed, CINAHL, SPORTDiscus, Scopus, and Discovery Layer. Studies were included if they examined the muscle activation of the upper trapezius compared to the middle trapezius, lower trapezius, or serratus anterior using EMG during open chain exercises. The participants were required to have healthy, nonpathological shoulders. Information obtained included maximal voluntary isometric contraction (MVIC) values, ratios, standard deviations, exercises, and exercise descriptions. The outcome of interest was determining exercises that create optimal muscle activation ratios between the scapular stabilizers.

Results: Fifteen observational studies met the inclusion criteria for the systematic review. Exercises with optimal ratios were eccentric exercises in the frontal and sagittal planes, especially flexion between 180° and 60°. External rotation exercises with the elbow flexed to 90° also had optimal ratios for activating the middle trapezius in prone and side-lying positions. Exercises with optimal ratios for the lower trapezius were prone flexion, high scapular retraction, and prone external rotation with the shoulder abducted to 90° and elbow flexed. Exercises with optimal ratios for the serratus anterior were the diagonal exercises and scapular protraction.

Conclusion: This review has identified optimal positions and exercises for periscapular stability exercises. Standing exercises tend to activate the upper trapezius at a higher ratio, especially during the 60-120° range. The upper trapezius was the least active, while performing exercises in prone, side-lying, and supine positions. More studies need to be conducted to examine these exercises in greater detail and confirm their consistency in producing the optimal ratios determined in this review.

Level of evidence: 1a

Keywords: Electromyography, electromyography feedback, resistance training, serratus anterior, trapezius
INTRODUCTION
The shoulder complex consists of the glenohumeral, acromioclavicular, sternoclavicular, and scapulothoracic joints, therefore, strengthening and stretching exercises for scapular stabilizing muscles are commonly used in rehabilitation of shoulder dysfunctions.1 During movement of the shoulder, the scapula and humerus are constantly changing positions relative to one another, making their ability to work in unison imperative to maintenance of stability of the glenohumeral joint. This phenomenon was coined scapulohumeral rhythm by Codman in 1934.2 During overhead activities, both the rotator cuff and periscapular musculature provide stability and aid in pain free mobility at the shoulder complex in healthy individuals.3 Force couples, which involve two opposing muscular forces working together to enable a particular joint motion, are important for optimal scapular stabilization during humeral movement.4

Currently, authors have suggested that abnormal scapular movement or dyskinesia may play a role in impingement syndrome, rotator cuff dysfunction, instability, and even neck pain.5,6 Prolonged overhead activity requires adequate endurance of the scapular musculature in order to maintain a consistent, proper scapulohumeral rhythm. Without the necessary endurance, subacromial impingement may occur due to improper scapular rotation.1,7,8,9 It was originally suggested that scapular dyskinesia was due to global weakness of the scapular musculature. However, recent research has shown that muscular imbalance may be the problem, not strength. It has been hypothesized that compensation through increased activation of the upper trapezius (UT) combined with decreased activation and control of the lower trapezius (LT)/middle trapezius (MT)/serratus anterior (SA) contributes to abnormal scapular motion.9 With this in mind, many current rehabilitation programs, which only focus on strengthening these muscles as a whole, may be inadequate for creating proper scapulohumeral rhythm.

Electromyography (EMG) is used to measure muscular activity. Many researchers have used EMG during various scapular stabilizing exercises in order to differentiate between activity of the UT, MT, LT, and SA during exercise. The majority of these studies have failed to address the optimal ratios of these muscles during relevant exercises.10-20 A select few authors have examined the optimal ratios during scapular stabilizing exercises.5,6,21,22 To obtain muscle ratios, the maximal voluntary isometric contraction (MVIC) of the examined muscles must be determined. The authors of this systematic review believe that this ratio is important when determining a individualized rehabilitation program to fit a certain patient. The purpose of this systematic review is to determine the exercises that optimize muscle ratios of the periscapular musculature for scapular stability and isolated strengthening.

METHODS
Literature Search
Articles were identified through a computerized search using PubMed, CINAHL, SPORTDiscus, Scopus, and Discovery Layer through Walsh University in November 2014. The search was performed using subject headings, abstract text, and key words for four main concepts: Trapezius, SA, exercise, and electromyography. In addition, these concepts were further specified and searched by the following key text words: Resistance training, EMG, and electromyography feedback. There were no restrictions placed on date of publication and type of study conducted. The searches were limited to English, Academic Journals, and humans. See appendices 1, 2, 3, 4, & 5 for the detailed search strategy. Although this review analyzed data only from a normal shoulder, due to risk of excluding eligible articles, there was no limit placed on the population sample during the search. (Appendix 1)

Study selection
Two reviewers (EB, JW) performed the initial screening of articles to determine eligibility. Two reviewers (AS, JQ) reviewed the included full text articles. Full text articles were reviewed if the abstract met the inclusion criteria, or if the abstract did not entail enough information to include or exclude the study. If there was a disagreement, a third reviewer was used to determine eligibility.

Eligibility criteria
To satisfy this review, EMG must be the primary tool used. A detailed description of methods of EMG normalization and analysis is required for
reproducibility, quality analysis of recommended guidelines, comparability, and continuity of appropriate usage and technology. Studies were included if they contained %MVIC/%MVC and/or muscle ratios as a way of standardizing data and measurement values. This ensures that comparisons could be made between data across the studies. It was required that the studies compare the EMG activity of the UT with at least one of the following muscles: MT, LT, or SA for determining muscle ratios during the exercises. In addition, studies must include two or more open-chain exercises, performed actively by the subjects, examining the same scapular muscles for comparison. The study had to include a group containing normal, non-pathological shoulders define muscle ratios in the asymptomatic, healthy shoulder.

Exclusion Criteria. Studies were excluded if all of their participants had a history of shoulder pathology or injury, scapular pathology, pain, or symptoms within the past two years in order to reduce the influence of these factors on the muscle activation ratios. Studies were excluded if they only examined closed-chain exercises, did not use EMG as a primary tool, and did not take a standardized approach for normalizing and analyzing EMG activity. Because of the plethora of literature involving both open and closed chain exercises, the researchers chose to focus this review on open-chain exercises.

Data collection process
Two reviewers (AS & JQ) extracted relevant data from the studies. One author was contacted in order to obtain the data tables from the study. Exercises from each study were reviewed for commonalities. If the studies included symptomatic or pathological participants, data only from the control groups was extracted.

Data Extraction
Information obtained from each study included MVIC values, ratios (if applicable), standard deviations, exercises, and exercise description, which can be fully viewed in Supplemental Tables 1-4 contained in Appendix 3 (Available in Supplemental materials, linked on the IJSPT Website).

Descriptions of each exercise were collected for comparison across studies. (Appendix 2) Study characteristics were also extracted and can be viewed in Table 1. Studies completed with and without resistance were included as long as the resistance was consistent within individual studies. Use of resistance should not theoretically significantly affect the muscle ratios for the performed exercise, allowing for comparison of ratios across studies. Data from exercises, with descriptions that were biomechanically homogenous across studies, were included in the same row of the %MVIC and ratio tables. If studies provided variables (%MVIC or ratio) for individual phases of exercise (concentric, isometric, eccentric), the values were averaged to give a mean representation of the muscle activity and/or ratio throughout the entire exercise. If studies reported EMG activity during exercise as %MVIC, the authors calculated the ratios using the %MVIC of the UT and %MVIC of another relevant muscle.

Ratios were calculated by dividing the %MVIC of the UT by %MVIC of another relevant muscle during the same exercise (UT/MT, UT/LT, UT/SA). Ratios could not be calculated between muscles that were not recorded during the same exercise. The authors suggest that optimal ratios for exercises targeting the MT, LT, and SA would be close one to one, indicating that these muscles were emphasized similarly with reference to the UT. A ratio that was greater than 1.00, indicated that the UT was more active than the other scapular stabilizers during the exercise. For the purpose of this study, ratios under 1.00 were considered exercises that were ideal, as often, rehabilitation professionals are looking for exercises that emphasize the scapular stabilizers other than the UT, attempting to decrease the risk of compensation with the UT.

Risk of bias in individual studies
Two reviewers (EB & JW) reviewed each study independently using a quality assessment chart for observational studies, created by Siegfried et al.23, 24 The chart was adapted for this review. This tool was chosen because it allows evaluation of observational studies' internal and external validity. Instead of providing a summary score, a checklist is provided to allow the readers to evaluate each study separately. Two reviewers compared their assessment of each study for agreement. The quality assessment can be viewed in Table 2.
<table>
<thead>
<tr>
<th>First Author, Year</th>
<th>Participants (N)</th>
<th>Age, mean (SD) and/or age range in years</th>
<th>Study Design</th>
<th>Exercises Tested</th>
<th>Muscles Assessed</th>
<th>Value Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cools, 2007</td>
<td>45</td>
<td>20.7 (1.7)</td>
<td>Observational</td>
<td>Vertical Pulley, v-bar Saption (30° anterior of frontal plane) with ER Dumbbell Side-lying ER with elbow flexed to 90° Dumbbell</td>
<td>UT, MT, LT, SA</td>
<td>Ratios, %MVIC</td>
</tr>
<tr>
<td>De Mey, 2012</td>
<td>30</td>
<td>20 (3.5) Range 18-30</td>
<td>Observational</td>
<td>High Scapular Retraction Exercises: Sitting Standing Static bipedal squat Static Lunge Static unipedal squat Dynamic bipedal squat Dynamic Lunge Dynamic unipedal squat</td>
<td>UT, LT</td>
<td>%MVIC</td>
</tr>
<tr>
<td>Decker, 1999</td>
<td>20</td>
<td>30.4 (5.1)</td>
<td>Observational</td>
<td>Scaption in 45° ER (thumb up) Dumbbell Dynamic Hug: elbow flexed 45°, arm abducted 60°, IR 45° to max. protraction</td>
<td>UT, SA</td>
<td>%MVIC</td>
</tr>
<tr>
<td>Cools, 2007</td>
<td>30</td>
<td>22.5 (4.3) Range 18 – 35</td>
<td>Observational</td>
<td>Isokinetic Abd 120°/s Isokinetic ER 60°/s</td>
<td>UT, MT, LT</td>
<td>Ratios, %MVIC</td>
</tr>
<tr>
<td>Cools, 2007</td>
<td>45</td>
<td>20.7 (1.7)</td>
<td>Observational</td>
<td>Prone Abduction Dumbbell Forward Flexion (FF) Dumbbell Forward Flexion in Side Lying to 135° Dumbbell High Row 135° FF to neutral position Vertical Pulley, v-bar Horizontal Abduction in prone Dumbbell Horizontal Abduction with ER in prone Dumbbell Low Row with elbows extended Vertical Pulley, v-bar Low Row with elbows flexed Vertical Pulley, v-bar Prone Extension Dumbbell Rowing in Sitting Position</td>
<td>UT, MT, LT, SA</td>
<td>Ratios, %MVIC</td>
</tr>
</tbody>
</table>
### Table 1. Characteristics of included studies (continued)

<table>
<thead>
<tr>
<th>First Author, Year</th>
<th>Participants (N)</th>
<th>Age, mean (SD) and/or age range in years</th>
<th>Study Design</th>
<th>Exercises Tested</th>
<th>Muscles Assessed</th>
<th>Value Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ekstrom, 2003</td>
<td>30</td>
<td>27.2 (2.7)</td>
<td>Observational</td>
<td>Unilateral shoulder shrug, Hanging Weight, Shoulder abduction in the plane of the scapula above 120° with LT muscle fibers, Dumbbell, Arm raise overhead in line Dumbbell, Shoulder abduction in the plane of the scapula below 80° Dumbbell, Shoulder horizontal extension with ER Dumbbell, Diagonal exercise with shoulder flexion, horizontal flexion, and ER Dumbbell, Unilateral row Hanging Weight, Shoulder ER at 90° of abduction Dumbbell, Unilateral shoulder press Barbell with Weights, Bilateral scapular protraction</td>
<td>UT, MT, LT, SA</td>
<td>%MVIC</td>
</tr>
<tr>
<td>Huang, 2012</td>
<td>12</td>
<td>23.8 (2.9)</td>
<td>Observational</td>
<td>Side-lying ER with elbow 90° flexion Dumbbell, Forward Flexion Dumbbell, Lawnmower Robbery</td>
<td>UT, MT, LT, SA</td>
<td>Ratios</td>
</tr>
<tr>
<td>Kibler, 2008</td>
<td>18</td>
<td>27.3 (4.4)</td>
<td>Observational</td>
<td>Prone horizontal abduction at 90° with full ER Dumbbell, Prone horizontal abduction at 90° abduction with middle ER Dumbbell, Prone horizontal abduction at 100° abduction with full ER Dumbbell, Prone ER at 90° abduction and elbow at 90° Dumbbell, Side-lying ER with elbow on trunk Dumbbell, Standing ER in scapular plane (45° abduction, 30° horizontal abduction) Dumbbell</td>
<td>UT, LT, SA</td>
<td>%MVIC</td>
</tr>
<tr>
<td>Marta, 2013</td>
<td>20</td>
<td>22 (3.6)</td>
<td>Observational</td>
<td>Prone horizontal abduction at 90° with full ER Dumbbell, Prone horizontal abduction at 90° abduction with middle ER Dumbbell, Prone horizontal abduction at 100° abduction with full ER Dumbbell, Prone ER at 90° abduction and elbow at 90° Dumbbell, Side-lying ER with elbow on trunk Dumbbell, Standing ER in scapular plane (45° abduction, 30° horizontal abduction) Dumbbell</td>
<td>UT, MT, LT</td>
<td>Ratios, %MVIC</td>
</tr>
</tbody>
</table>
RESULTS

Study selection
The initial search yielded 634 results. After removing duplicates, the titles and abstracts were screened for 296 articles. Thirty-two studies were included for full text review. After full text review, 15 studies met the inclusion criteria to be included in this review. Refer to Figure 1.

### Table 1. Characteristics of included studies (continued)

<table>
<thead>
<tr>
<th>First Author, Year</th>
<th>Participants (N)</th>
<th>Age, mean (SD) and/or age range in years</th>
<th>Study Design</th>
<th>Exercises Tested</th>
<th>Muscles Assessed</th>
<th>Value Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marta, 2013</td>
<td>20</td>
<td>22 (3.6) Range 16 - 34</td>
<td>Observational</td>
<td>Standing ER with towel Dumbbell Rowing Horizontal abduction (neutral) Horizontal abduction with ER</td>
<td>UT, MT, LT</td>
<td>Ratios, %MVIC</td>
</tr>
<tr>
<td>Moseley, 1992</td>
<td>9</td>
<td>Range 22 – 34</td>
<td>Observational</td>
<td></td>
<td>UT, MT, LT</td>
<td>%MVIC</td>
</tr>
<tr>
<td>Oliveira, 2012</td>
<td>15</td>
<td>20.27 (1.79)</td>
<td>Observational</td>
<td></td>
<td>UT, LT, SA</td>
<td>Ratios, %MVIC</td>
</tr>
<tr>
<td>Pizzari, 2013</td>
<td>23</td>
<td>Range 18 – 37</td>
<td>Observational</td>
<td>Shrug at 0° abduction Shrug at 30° abduction</td>
<td>UT, MT, LT, SA</td>
<td>%MVIC</td>
</tr>
<tr>
<td>Sciascia, 2012</td>
<td>10</td>
<td>21 (3.3)</td>
<td>Observational</td>
<td>Scaption: 30°, 60°, 90°, 120° Prone horizontal abduction 30°, 60°, 90°, 120°</td>
<td>UT, SA</td>
<td>%MVIC</td>
</tr>
<tr>
<td>Sciascia, 2012</td>
<td>10</td>
<td>21 (3.3)</td>
<td>Observational</td>
<td>Prone ER 30°, 60°, 90°</td>
<td>UT, SA</td>
<td>%MVIC</td>
</tr>
<tr>
<td>Wattanaprapornkul, 2011</td>
<td>15</td>
<td>21.9 (3.0)</td>
<td>Observational</td>
<td></td>
<td>UT, LT, SA</td>
<td>%MVIC</td>
</tr>
</tbody>
</table>

UT = upper trapezius  
MT = middle trapezius  
LT = lower trapezius  
SA = serratus anterior  
MVIC = maximal voluntary isometric contraction  
Scaption = shoulder elevation 45° anterior to the frontal plane; 45° shoulder abduction with 30° horizontal abduction  
FF = forward flexion  
ER = external rotation
### Table 2. Quality Assessment of Cross-Sectional Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>External Validity</th>
<th>Performance</th>
<th>Detection</th>
<th>Internal Validity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Representative</td>
<td>Direct Observation</td>
<td>Blinded Assessors</td>
<td>Randomization of Exercises</td>
</tr>
<tr>
<td>Cools et al.\textsuperscript{5}</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cools et al.\textsuperscript{21}</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>De Mey et al.\textsuperscript{10}</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decker et al.\textsuperscript{11}</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ekstrom et al.\textsuperscript{12}</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Huang et al.\textsuperscript{6}</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Kübler et al.\textsuperscript{13}</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
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<tr>
<td>Marta et al.\textsuperscript{14}</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Moseley et al.\textsuperscript{15}</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Oliveira et al.\textsuperscript{22}</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Park et al.\textsuperscript{16}</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pizzari et al.\textsuperscript{17}</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sciaccia et al.\textsuperscript{18}</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
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<tr>
<td>Uhl et al.\textsuperscript{19}</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wattanaprapornkul et al.\textsuperscript{20}</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:**
- **Representative:** study was representative of the population by including both males and females
- **Participation rate:** all of the participants completed the study; no drop-outs
- **Physical examination:** participants underwent a physical examination by a profession prior to the study
- **Standardization of exercise technique:** studies controlled for speed and component of movements performed by the participants

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**Figure 1.** *Prisma flowchart for research strategy.*
Study Characteristics

Study Design
All 15 studies included were observational studies. For all studies, testing and EMG data collection occurred within the same day. Standardization of exercise techniques was used in 13 of the 15 studies included.\textsuperscript{5,6,10,11,12,13,14,16,17,18,20,21,22} Four studies provided a physical examination for the participants prior to the start of the study.\textsuperscript{5,6,18}

Participants
Three studies included only male participants.\textsuperscript{11,14,22} None of the studies had any dropouts. Table 1 includes participant age characteristics for each study.

Risk of bias within studies
Three studies included a physical examination by a professional prior to the start of the exercises in order to assure normal scapulohumeral rhythm in the normal shoulders.\textsuperscript{5,6,18} Internal validity was compromised in the other studies, all of which did not control for the presence or absence of scapular dyskinesia. There were also biases among the studies for normalization and EMG standardization procedures, which could explain the differences in EMG values across studies during similar exercises. Two studies did not use a standardized technique (metronome) for exercise performance to assure continuity throughout the study.\textsuperscript{15,19} However, all studies allowed practice sessions for participants to become accustomed to the motions expected. One study,\textsuperscript{16} only reported EMG data for the eccentric phase of the exercises, leaving out the concentric and isometric phases. Although relevant for the purposes of this study, it may decrease the external validity by decreasing applicability to the general population, due to not comprising all phases of the exercise motion.\textsuperscript{25} Furthermore, five studies did not randomize the order in which exercises were performed, which is a risk for selection bias. This could induce fatigue, which could subsequently lower the %MVIC or promote compensation during the later exercises.\textsuperscript{26} None of the studies included blinded assessors, which is a risk for increasing biases. However, due to the observational nature of the studies included, the use of blinded assessors is not possible.

Refer to Table 2 to view the quality assessment of internal and external validity among each study.

Results of individual muscles

Upper Trapezius. The UT muscle was analyzed in each of the studies. The most common exercises were variations of shoulder abduction. The UT was highly active during the rowing motion reported by Moseley et al.\textsuperscript{15} Other exercises in which the trapezius was highly active were abduction to 120°, the shoulder/scapular shrug, and abduction in the scapular plane to 90° with the shoulder externally rotated.\textsuperscript{5,11,12,17,18,22}

Exercises with ratios that favored the UT over the other scapular stabilizers include: Maximal forward flexion, shoulder shrug, and abduction with external rotation. See Tables 3, 4, and 5 for ratios for each exercise. Table 1 in Appendix 3 presents %MVIC values of the UT during each exercise, across all studies. (Available in Supplemental materials, linked on the IJSPT Website)

Middle Trapezius. The MT muscle was highly active during eccentric abduction and flexion.\textsuperscript{16} It was also highly active during prone overhead raise, prone

| Table 3. Upper Trapezius/Middle Trapezius. Optimal Ratios. |
|---------------------------------|-----|-----|-----|-----|-----|
| Coeks, et al\textsuperscript{11} | Eksel, et al\textsuperscript{12} | Huang, et al\textsuperscript{14} | Kibler, et al\textsuperscript{15} | Marta, et al\textsuperscript{16} | Park, et al\textsuperscript{16} |
| Abduction 60°, Eccentric Abduction | 0.46 |
| 180°, Eccentric Flexion 180°, Eccentric Prone ER at 90° abd, 90° elbow flexion Side-lying ER with elbow at 90° | 0.38 |
| 0.37 | 0.44 | 0.54* | 0.38 | 0.44 |
| * Indicates ratios were reported in the study and were not calculated by authors Studies were not included in table if they did not report on the above exercises ER = external rotation Values rounded to the nearest hundredth. |
Exercises with optimal ratios (ratios that favored MT activity with little UT activity) were eccentric exercises in the frontal and sagittal planes, especially flexion between 180° and 60°. External rotation exercises with the elbow flexed to 90° also had optimal ratios for activating the MT in prone and side-lying positions. Table 3 displays data for all UT/MT ratios. See Table 2 in Appendix 3 for %MVIC values of the MT during each exercise. (Available in Supplemental materials, linked on the IJSPT Website)

**Typically**

**Lower Trapezius.** The LT muscle was highly active during prone flexion, prone overhead raise, and prone external rotation. Exercises in the scapular plane did not activate the LT as much as the other scapular stabilizers.

Exercises with optimal ratios for the LT were prone flexion, high scapular retraction, and prone external rotation with the shoulder abducted to 90° and elbow flexed. The least optimal ratios were during shoulder abduction and press-up exercises done in a standing or semi-reclined position. See Table 4 for all UT/LT ratios. See Table 3 in Appendix 3 for %MVIC values of the LT during each exercise. (Available in Supplemental materials, linked on the IJSPT Website)

**Serratus Anterior.** The SA muscle was most active during exercises that involved reaching across the body, such as, the dynamic hug and diagonal exercise. It was also the most active of the scapular muscles during side-lying forward flexion. Abduction in the scapular plane with external rotation activated the SA more if elevation exceeded 80°.22

Exercises with optimal ratios for the SA were the diagonal exercises and scapular protraction. The bench press exercise and supine press also provided optimal ratios. Shoulder shrug, low row, and abduction with external rotation in prone provided the least optimal ratios for SA activation. See Table 5 for all UT/SA ratios. See Table 4 in Appendix 3 for %MVIC values for the SA during each exercise.

### Table 4. **Upper Trapezius/Lower Trapezius**

<table>
<thead>
<tr>
<th>Exercise</th>
<th>DeMay et al.</th>
<th>Ekstrom et al.</th>
<th>Marta et al.</th>
<th>Waitanraprutikul et al.</th>
<th>Optimal Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>High SR, Sitting</td>
<td>0.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High SR, Standing</td>
<td>0.28</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prone ER with Shoulder Abducted to 90°</td>
<td></td>
<td>0.25</td>
<td>0.79</td>
<td></td>
<td>0.06</td>
</tr>
<tr>
<td>Prone Flexion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† Indicates measurements were estimated from a graph
Studies were not included in table if they did not report on the above exercises
ER = external rotation
SR = scapular retraction
Values rounded to the nearest hundredth

### Least Optimal Ratios and SD (when applicable)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Abduction to 45°</td>
<td></td>
<td>1.57 (0.55)</td>
<td></td>
</tr>
<tr>
<td>Abduction to 90°</td>
<td></td>
<td>1.35 (0.51)</td>
<td></td>
</tr>
<tr>
<td>Abduction to 120°</td>
<td>1.36</td>
<td>1.18 (0.62)</td>
<td></td>
</tr>
<tr>
<td>Abduction in scapulation to 45°</td>
<td></td>
<td>1.19 (0.56)</td>
<td></td>
</tr>
<tr>
<td>Abduction in scapulation to 90°</td>
<td></td>
<td>0.99 (0.18)</td>
<td></td>
</tr>
<tr>
<td>Abduction in scapulation to 120°</td>
<td></td>
<td>1.05 (0.50)</td>
<td></td>
</tr>
<tr>
<td>Press Up, Standing</td>
<td></td>
<td></td>
<td>2.67</td>
</tr>
<tr>
<td>Wedge Press Up (Reclined)</td>
<td></td>
<td></td>
<td>5.50</td>
</tr>
</tbody>
</table>

Scaption = shoulder elevation in the scapular plane (45° anterior to the frontal plane)
Values rounded to nearest hundredth
DISCUSSION

Summary of evidence

The results of this review illustrate the variations of common shoulder exercises, and their impact on muscle ratios in the scapular stabilizers. The authors performed a quality assessment in order to determine the risk of bias and interpret the quality of results. When interpreting significance of the results, the number of studies that examined a specific exercise and found similar results was considered. This was a consideration due the inclusion of 62 exercises, most of which were not examined in more than one study. Therefore, comparisons of EMG activity and ratios across studies were limited.

For the MT, this review revealed that the eccentric phase of flexion exercises from 180° and 60° promoted optimal ratios. However, when the average of all phases of shoulder flexion were analyzed in other studies, ratios exceeded 1.00. This indicates that the UT is more active than the MT. Therefore, if trying to activate the MT with the least amount of UT activity, only the eccentric phase should be performed. Isolating only one phase while performing an exercise is not typical practice of the general population. With relevance to clinical application, it is not functional to perform only one phase/type of contraction during dynamic exercises and activities as concentric and eccentric motions are often paired. During the prone unilateral row exercise, the MT was the only scapular stabilizer that was more activated than the UT. Another interesting finding represented by the data was the effect of the variations of the row exercise. This review shows that a rowing motion (shoulder extension) with the elbows extended promotes higher activation and a more favorable ratio in the MT muscle when compared to a traditional row (shoulder extension with elbow flexion). The UT/SA ratio during the low row exercise with elbows extended is approximately 1.00, which indicates that during this motion, the MT is

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Optimal Ratios</th>
<th>Least Optimal Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bench Press, Seated</td>
<td>0.11</td>
<td>0.30</td>
</tr>
<tr>
<td>Diagonal Exercise</td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td>Bilateral Scapular</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>Protraction</td>
<td>0.06</td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Upper Trapezius/Serratus Anterior.

- Indicates measurements were estimated from a graph
- Studies were not included in table if they did not report on the above exercises
- Values rounded to the nearest hundredth

(Available in Supplemental materials, linked on the IJSPT Website)
In relation to the purpose of this review, exercises that promoted higher UT activity when compared to the other scapular stabilizers were also determined. If the target muscle is the SA, this review determined that prone horizontal abduction (with or without ER) and prone unilateral row exercises should be avoided. The UT was significantly more active than the LT during exercises in the scapular plane. The shoulder shrug exercises at 0° and 30° abduction produced UT muscle activation that was double to quadruple that of the comparison scapular muscles. A narrative review by Cricchio & Frazer reported similar findings in exercises that primarily activated the MT, LT, and/or SA. Consistent with the current findings, those authors also reported overhead arm raise at 125° activated the MT and LT, indicating less activation of the UT at elevation above 120°. The narrative also determined prone exercises to be beneficial for activating the MT, as well as recommending side-lying and prone exercises for low UT/LT ratios. In terms of this review, low ratios reported in the narrative would be optimal.

In order to perform elevation activities, proper muscle activation is essential. Limiting UT muscle activation while the force couple of the MT, LT, and SA are activated is vital to prevent abnormal mechanics or symptoms. Appropriate exercise choices are vital in order to properly address muscle weakness that may be contributing to altered movement patterns. According to this review, best choices for the MT include prone external rotation and side-lying external rotation. During external rotation, the MT may be activated because of the need for retraction of the scapula as well as maintaining an optimal length of the external rotators as the movement is being performed.

The ideal exercises for the LT were prone flexion, high scapular retraction, and prone ER. These exercises are common utilized clinically and the movement is in proper alignment with the fiber direction of the LT.

The most effective SA exercises were the diagonal exercise, scapular protraction, bench press, and supine press. All of these exercises promote protraction and upward rotation of the scapula which...
are primary movements produced by the serratus anterior. Finally, clinicians should attempt to limit utilizing exercises that activate the UT excessively, such as the shoulder shrug, prone unilateral row and prone horizontal abduction.

**Review Limitations**

Although the %MVIC was used to calculate ratios, it could not be used to determine optimal exercises for individual muscles. This is due to the inconsistencies between normalization techniques and resistance used across studies that performed the same exercises. There were also differences in methodology across studies that make it difficult to compare similar exercises. The many variations of the exercises included in these studies also could account for discrepancies in muscles activity across the studies. Some studies recorded the concentric, isometric, and eccentric phases of the exercise separately. Averaging these values, rather than having the entire exercises recorded and averaged via EMG analysis, could account for variation from the true value. Furthermore, estimations made from the graphs in Wattanaprakornkul et al allowed for variation by interpretation.

Authors (AS, JQ, and JW) were unilingual and therefore unable to include studies in languages other than English. Many exercises were only reviewed in one article, giving us no aspect of inter-rater reliability or comparison across studies. Most studies only included %MVIC; therefore, ratios were calculated independently and not by the original researchers and standard deviations could not be calculated. Although load/resistance differences used between studies should not alter the biomechanics of the exercise, and therefore should not significantly alter the muscle activation ratios, compensation is more likely with increased loads, fatigue, or pathology. If compensation did occur, this may have impacted muscle activity and subsequent muscle ratios. Muscle ratios were calculated without consideration or separation of exercises according to muscle contraction type (eccentric, isometric, concentric). Therefore, caution should be noted in the selection of exercises based strictly on muscle contraction type. Due to no reporting of participants undergoing imaging prior to the studies, the authors do not know of any underlying pathologies that may have been present that could alter the biomechanics of the shoulder. Because tissue healing may take 1-3 years to gain 100% of normal tensile strength post injury exclusion criteria was set at two years, which may have allowed for decreased strength in previously injured participants included within these studies.

The recommendations from this review are based on studies and calculations made on healthy, non-pathological subjects. Therefore, the results of this review can only be used to inform guidelines for a rehabilitation program to be used with injured patients or clients. Further research is needed to determine the applicability of these results to a rehabilitation program for pathological shoulders. Future studies should also be performed with consistent parameters to improve continuity of results.

**CONCLUSION**

This review has identified optimal positions and exercises related to periscapular muscular recruitment and stability exercises. In general, standing exercises tend to activate the UT at a higher ratio than the MT, LT, and SA, especially during the 60-120° range. The UT was the least active, relative to the other scapular muscles examined, while performing exercises in prone, side-lying, and supine positions; and which one of these positions is recommended is dependent upon the exercise and whether the target muscle is the MT, LT, or SA. More studies need to be conducted to examine these exercises in greater detail and confirm their consistency in producing the optimal ratios determined in this review. Further investigation is required to determine the similarities and/or differences in the muscle ratios in subjects with healthy versus pathological shoulders.

**REFERENCES:**

2. Codman EA. The Shoulder: Rupture of the Supraspinatus Tendon and Other Lesions In or About the Subacromial Bursa. Boston: Thomas Todd Co.; 1934.


APPENDIX 1: DETAILS OF SEARCH STRATEGY AND INCLUSION/EXCLUSION CRITERIA

PubMed Search Strategy
1. Trapezius [Text Word]
2. Serratus Anterior [Text Word]
3. 1 OR 2
4. Exercise Therapy [MeSH Terms]
5. Exercise* [MeSH Terms]
6. Resistance Training [MeSH Terms]
7. Exercise* [Text Word]
8. 4 OR 5 OR 6 OR 7
9. Electromyography [MeSH Terms]
10. Electromyography feedback [MeSH Terms]
11. Electromyography [Text Word]
12. EMG [Text Word]
13. 9 OR 10 OR 11 OR 12
14. 3 & 8 & 13
Filters: Humans, English

Discovery Layer (Walsh University) Search Strategy
1. Trapezius (AB abstract)
2. Resistance Exercise (TX All Text)
3. EMG (TX All Text)
4. 1 & 2 & 3
Limit: English, Academic Journal

CIHNAL Search Strategy
1. Serratus Anterior OR Trapezius
2. Exercise
3. EMG
4. 1 & 2 & 3
Limit: English, Academic Journal

SPORTDiscus Search Strategy
1. Trapezius (AB abstract)
2. Exercise (TX All Text)
3. Electromyography (TX All Text)
4. 1 & 2 & 3
Limit: English & Academic Journal

Scopus Search Strategy
1. Trapezius OR Serratus Anterior
2. Resistance Training OR exercise
3. EMG OR electromyography
4. 1 & 2 & 3
Limit: English, Human, Article, Review

Inclusion Criteria
1. English
2. Academic Journal
3. EMG used as primary tool
4. EMG analysis of the UT and at least one of the following muscles: MT, LT, or SA
5. Compare EMG activity of one or more of the above muscles during two or more active open-chain exercises
6. Normal, healthy, asymptomatic shoulder
7. Include %MVIC/MVC and/or ratio values for data standardization and continuity of measurement across studies
8. Method of normalization of EMG for improved quality and comparability of values
9. Detailed method of EMG analysis for all muscles tested or statement of guidelines followed for reproducibility, quality analysis, and continuity of appropriate usage and technology.

Exclusion Criteria
1. History of shoulder pathology within 2 years
2. History/current scapular pathology
3. Symptomatic/Pain within 2 years
4. Closed-Chain Exercises
5. No standardized approach for EMG normalization and analysis EMG not used as primary tool
### Appendix 2  *Upper Trapezius/Lower Trapezius*

<table>
<thead>
<tr>
<th>Exercise Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abduction</td>
</tr>
<tr>
<td>Shoulder abduction in the frontal plane with the shoulder in neutral position of rotation (palm down)</td>
</tr>
<tr>
<td>Abduction in scaption</td>
</tr>
<tr>
<td>Shoulder abduction in the scapular plane with the shoulder in a neutral position (palm down)</td>
</tr>
<tr>
<td>Abduction, maximal</td>
</tr>
<tr>
<td>Abduction in the frontal plane with the shoulder in neutral position (palm down) to the subject’s maximum range</td>
</tr>
<tr>
<td>Bench Press, seated</td>
</tr>
<tr>
<td>Seated chest press using a weight machine; Starting position with shoulders abducted to 90°, elbows flexed, scapular retraction, forearm pronation; Ending position with scapular protraction, horizontal shoulder adduction, elbow extension</td>
</tr>
<tr>
<td>Bilateral scapular protraction</td>
</tr>
<tr>
<td>Supine; Bilateral scapular protraction with the shoulder horizontally flexed to about 45° and the elbows flexed to about 45°</td>
</tr>
<tr>
<td>Diagonal exercise</td>
</tr>
<tr>
<td>Combination of shoulder flexion, horizontal flexion, and external rotation in the sitting position</td>
</tr>
<tr>
<td>Diagonal – eccentric</td>
</tr>
<tr>
<td>Shoulder neutral rotation and 30° horizontal flexion; starting position in 130° shoulder abduction; ending position with full shoulder internal rotation</td>
</tr>
<tr>
<td>Dynamic Hug</td>
</tr>
<tr>
<td>Standing with back toward the wall, knees slightly bent, and the feet shoulder-width apart; Being with elbow flexed 45°, shoulder abducted 60°, and shoulder internally rotated 45°; Horizontally flex shoulder following an arc (hugging motion) until maximum protraction is attained</td>
</tr>
<tr>
<td>ER in scapular plane</td>
</tr>
<tr>
<td>Shoulder external rotation in the scapular plane (45° abduction, 30° horizontal abduction) with the elbow flexed to 90°</td>
</tr>
<tr>
<td>Extension, prone</td>
</tr>
<tr>
<td>Prone with shoulders resting in 90° forward flexion; Extension to neutral position with the shoulder in neutral rotation</td>
</tr>
<tr>
<td>Flexion – Eccentric</td>
</tr>
<tr>
<td>Shoulder in neutral rotation and 70° horizontal flexion; Start at 130° shoulder flexion; End at 40° shoulder flexion with full internal rotation</td>
</tr>
<tr>
<td>Forward flexion, maximal</td>
</tr>
<tr>
<td>Standing; Shoulder in neutral position; perform maximal forward flexion in the sagittal plane</td>
</tr>
<tr>
<td>Forward flexion, side-lying</td>
</tr>
<tr>
<td>Side-lying position, should in neutral position; perform forward flexion in a horizontal plane to 135°</td>
</tr>
<tr>
<td>High row</td>
</tr>
<tr>
<td>Standing in front of a vertical pulley with shoulders in 135° forward flexion; performs shoulder extension to neutral position</td>
</tr>
<tr>
<td>High SR, sitting</td>
</tr>
<tr>
<td>Trunk supported, feet on the ground; 1m away from pulley apparatus; starting with scapular protraction, high scapular retraction was performed until the elbows were positioned at the lateral side of the trunk; maintain neutral spine</td>
</tr>
<tr>
<td>High SR, standing</td>
</tr>
<tr>
<td>Feet positioned shoulder width, legs straight; 1m away from pulley apparatus; starting with scapular protraction, high scapular retraction was performed until the elbows were positioned at the lateral side of the trunk; maintain neutral spine</td>
</tr>
<tr>
<td>High SR, static bipedal squat</td>
</tr>
<tr>
<td>Feet shoulder width apart with both knees positioned at 90° above the feet; 1m away from pulley apparatus; starting with scapular protraction, high scapular retraction was performed until the elbows were positioned at the lateral side of the trunk; maintain neutral spine</td>
</tr>
<tr>
<td>High SR, static lunge</td>
</tr>
<tr>
<td>Contralateral leg in front with the knee in a 90° angle. Distance between both feet determined by taking the distance between the ASIS and the medial malleolus of the dominant side; 1m away from pulley apparatus; starting with scapular protraction, high scapular retraction was performed until the elbows were positioned at the lateral side of the trunk; maintain neutral spine</td>
</tr>
<tr>
<td>High SR, static unipedal squat</td>
</tr>
<tr>
<td>Contralateral knee placed above the foot in a 45° angle. 1m away from pulley apparatus; starting with scapular protraction, high scapular retraction was performed until the elbows were positioned at the lateral side of the trunk; maintain neutral spine</td>
</tr>
<tr>
<td>High SR, dynamic bipedal squat</td>
</tr>
<tr>
<td>Starting position as static version. Concentric phase of arm movement during concentric squat</td>
</tr>
<tr>
<td>Table 1</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>High SK, dynamic lunge</td>
</tr>
<tr>
<td>High SK, dynamic unipedal squat</td>
</tr>
<tr>
<td>Ipsilateral step-up with ball</td>
</tr>
<tr>
<td>Ipsilateral shoulder flexion</td>
</tr>
<tr>
<td>Lawnmower</td>
</tr>
<tr>
<td>Low row 1</td>
</tr>
<tr>
<td>Low row 2</td>
</tr>
<tr>
<td>Prone abduction with ER</td>
</tr>
<tr>
<td>Prone horizontal abduction at 90° forward flexion</td>
</tr>
<tr>
<td>Prone horizontal abduction at 100° forward flexion</td>
</tr>
<tr>
<td>Prone horizontal abduction with ER</td>
</tr>
<tr>
<td>Prone overhead raise</td>
</tr>
<tr>
<td>Robbery</td>
</tr>
<tr>
<td>Row, seated</td>
</tr>
<tr>
<td>Scaption</td>
</tr>
<tr>
<td>Side-lying ER with elbow at 90°</td>
</tr>
<tr>
<td>Standing press-up</td>
</tr>
<tr>
<td>Supine shoulder press</td>
</tr>
<tr>
<td>Unilateral row, prone</td>
</tr>
<tr>
<td>Wedge press-up</td>
</tr>
</tbody>
</table>
ABSTRACT

Background: Physical activity and sports can be associated with low back pain. However, little is known about the relationship between core stability and nonspecific low back pain (LBP) among athletes.

Purpose: The purpose of this study was to investigate the relationship between core endurance and back dysfunction in collegiate male athletes with and without nonspecific LBP.

Methods: Fifty-five male collegiate athletes from a variety of sports were recruited for this study. Their mean age was 21.50 ± (2.54) years, mean weight was 70.96 ± (5.33) kg., and mean height was 174.38 ± (4.37) cm. Thirty athletes with non-specific LBP and twenty five healthy athletes were assessed using McGill's anterior, posterior, and left and right plank core endurance tests (seconds) and for dysfunction using the Micheli functional scale (MFS). Pearson's product moment correlations examined the relationships between core endurance and MFS.

Results: There were significant differences regarding the measured core endurance tests between the healthy athletes group and the nonspecific LBP group (p <0.05). Additionally, good negative (r = -0.794) and moderate negative (r = -0.541) correlations were found between MFS and trunk extensor and flexor endurance tests, respectively in the group with nonspecific LBP.

Conclusion: The results of this study imply that poor core endurance is likely associated with nonspecific LBP in collegiate athletes. Injury risk reduction and back management programs for the athletic population should include strategies that emphasize endurance of the core muscles especially the trunk extensors and flexors.

Level of Evidence: 2b

Keywords: collegiate athletes, low back pain, trunk endurance

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INTRODUCTION

Exceptional performance during sport is considered the ultimate goal of all training programs specifically designed for athletes. This goal can be achieved effectively through specific exercises that target the strength and endurance of the core musculature.1 The core plays an important role in stabilizing the peripheral joints and reducing the risk for injury especially during high levels of physical activity.2 Moreover, core stability has been proven to promote efficient body mechanics, allowing the athlete to maximize force production while minimizing loads placed on proximal joints. This is especially important during complex movements, such as: running, jumping, swimming, throwing, and hitting a volleyball.3,4

Core musculature includes the abdominals anteriorly, the paraspinals and gluteals posteriorly, the diaphragm superiorly, and the pelvic floor and hip girdle musculature inferiorly.5,6 In trained athletes, the core musculature is activated through a feed-forward mechanism shortly before movements of the upper and lower extremities to act as a foundation upon which skilled movements can be performed.7 Positive relations have been reported between core stability training and athletic performance using measures such as agility time, vertical jump height, kicking performance, and throwing accuracy.8,9

Low back pain (LBP) accounts for 30% of the musculoskeletal complaints occurring among the athletic population.10 Despite this high incidence, the etiology of chronic nonspecific LBP is not clearly understood, which increases the difficulty in developing effective treatment programs.4 LBP is considered one of the most common reasons for missing playing time in competitive athletes.11 The relationship between LBP and physical activity has been shown to be curvilinear in adolescents, considering that extremely low and high values of physical activity are associated with an increased risk of back pain.12

Poor trunk control during athletic activities is proposed to be a contributing factor to nonspecific LBP. It has been reported that recurrent nonspecific LBP is associated with altered motor coordination13 and increased fatigability of the trunk muscles.14 Hence, the faulty movement patterns characterized by early dominant activation of trunk muscles and delayed activation of synergistic muscles can cause instability and excessive joint motion with increased risks for dysfunction and pain.15

Individuals with nonspecific LBP have also been shown to exhibit decreased whole-body balance and lumbar position sense compared to asymptomatic individuals.16-18 Core stability interventions have been demonstrated to be effective in changing spinal muscle recruitment patterns as measured by electromyography in individuals with nonspecific LBP.19 There is lack of research on the correlation between core endurance and nonspecific LBP dysfunction. Therefore, the purpose of this study was to investigate the relationship between core endurance and back dysfunction in collegiate male athletes with and without nonspecific LBP.

METHODS

Participants
Fifty-five male collegiate athletes were recruited for this study. Several team sports were represented in this sample, including soccer, basketball, handball, and volleyball. Thirty athletes with nonspecific LBP were recruited from the college sports injuries clinic. This study group was matched with twenty-five healthy athletes, as control group. Table 1 presents the demographic data of participants.

Collegiate athletes with nonspecific LBP who had pain for more than three months with positive prone instability test were eligible.20 The prone instability test has a sensitivity of 0.72 and is used to identify individuals who demonstrate lumbar segmental instability with poor muscular control, a common deficit that is associated with non specific LBP.13 Exclusion criteria included refusal to participate in the study, LBP as a result of a specific spinal disease, infection, presence of a tumor, osteoporosis, fracture, structural deformity, inflammatory disorder, radicular symptoms, or cauda equina syndrome.21 The study was authorized by the Ethics and Research Committee of the Batterjaa Medical College. All participants signed a written informed consent and agreed with the study in advance.

Recruitment took place in two steps: First, a sports injury specialist, with Ph.D degree in orthopedic and
sports physical therapy, identified the potentially eligible athletes with nonspecific LBP and referred them to the university biomechanics lab. Second, the researcher conducted a screening for inclusion and exclusion criteria in order to make the final decision regarding eligibility to participate in the study. Once included, the prone instability test was performed, with the athlete laying prone with the body on the examining table and legs over the edge and feet resting on the floor with the trunk muscles are relaxed. The examiner applied posterior to anterior pressure to an individual spinous process of the lumbar spine and any provocation of pain was reported. Then the patient lifted the legs off the floor and posterior to anterior compression was applied again to the lumbar spine while the trunk musculature was contracted. The test was considered positive if pain was present in the resting position but subsided in the second position, suggesting that the muscle activation is capable of stabilizing the spinal segment.20 Twenty-five collegiate athletes without LBP volunteered to participate in the study, as the control group. All participants were provided with oral and written information about the study.

**Procedures**

All testing was performed in a single session in a controlled research laboratory. The same investigators measured the same tasks throughout the study. The following were the standard measures used for both groups:

**Micheli Functional Scale (MFS):** The MFS is a 5-item questionnaire consisting of a symptom question, three activity-related questions (extension, flexion, and jumping), and Visual Analogue Scale (VAS). The questionnaire is designed to assess symptoms of back pain and ease or difficulty during performance of various sporting activities relative to low back pain. Responses from the symptom questionnaire are scored from 0 to 5 points while the total score for the three activity questions is scored from 0 to 10 points (extension, 0-4; flexion, 0-3; jumping, 0-3). The visual analog scale is scored from zero (no pain at all) to ten (worst pain) based on a 10-cm line. Overall score is determined by adding the questionnaire responses to the VAS score. This maximum score possible is twenty-five. This number is then multiplied by 4 in order to result in a range of final scores from 0 to 100. A score of 0 is optimal and indicates the least amount of dysfunction, while a score of one hundred indicates maximal dysfunction. The MFS is a valid and reliable instrument for assessing pain and functional levels in the young athletes between 12 to 22 years.22

**McGill’s core endurance tests:** McGill’s tests were used to examine participants’ core endurance. These tests consisted of four positions: the trunk anterior flexor test, the right and left lateral plank, and trunk posterior extensor test.23 Participants performed one practice trial that lasted a few seconds to confirm correct positioning and then one test trial was recorded per position where the maximum time (seconds) participants could maintain a static position was measured. The same investigator visually determined the end of all tests to assure reliability of testing. This investigator used the commands ‘start’ and ‘stop’ to initiate and conclude the test while an assistant investigator recorded the times using a stopwatch. During the trunk posterior extensor test the assistant held straps to stabilize the lower body and the investigator determined the start and end of the test. The order of the four test positions was randomly assigned.

**Table 1. Demographic data of participants**

<table>
<thead>
<tr>
<th></th>
<th>Athletes with LBP, (n=30)</th>
<th>Athletes without LBP, (n=25)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>21.05 ± 2.59</td>
<td>22.06 ± 2.42</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>70.60 ± 4.85</td>
<td>71.40 ± 5.94</td>
</tr>
<tr>
<td>Height, cm</td>
<td>173.33 ± 4.41</td>
<td>175.64 ± 4.06</td>
</tr>
</tbody>
</table>

*Note: no statistically significant differences existed between groups.*
During the trunk anterior flexor test, participants sat with the trunk flexed to sixty degree with their hands across their chest and both knees flexed to ninety degree. Trunk and knee flexion were both determined using an electronic goniometer. Time was initiated when the participants assumed the measured position (Figure 1A), and stopped when the trunk deviated forward or backward from the 60º angle.

For the left lateral musculature plank test, participants' feet were placed one on top of the other, the right arm was perpendicular to the floor, elbow resting on the mat, with the left arm across the chest and the left hand on the right shoulder (Figure 1B). A similar position was utilized for the right lateral musculature plank test, with the left arm perpendicular to the floor (Figure 1C). Time was stopped when the investigator visually determined that the line between the participants' trunk or lower body segments (thigh or shank) was not maintained.

For the trunk posterior extensor test, participants laid prone on an examination table with both ASIS's on the edge of the table with their hands on the seat of a chair placed in front of them at the edge of the table. An assistant held the lower extremities above and below participants' knees in order to secure the lower body (Figure 1D). Time was started when participants assumed a horizontal position of the trunk, removed their hands from the chair and then crossed them across their chest, and time was stopped when participants were unable to remain in that position.

**Statistical Analysis**

Data were analyzed using Statistical Package for Social Sciences (SPSS) for Windows version 16.0 (SPSS, Inc., Chicago, Illinois). As a prerequisite for parametric calculations for the analysis of difference analysis of relationship measures, data were screened for normality assumptions. Multivariant analysis of variance (MANOVA) test was used to analyze the difference between the healthy and nonspecific LBP groups. Then, Pearson's product moment correlations were used to examine relationships between core endurance and back dysfunction level. An apriori alpha level of 0.05 was used.

**Figure 1.** Core Endurance tests of McGill. A. Flexor endurance test, B. Left side plank, C. Right side plank, D. Extensor endurance test, note therapist stabilization of the lower body.
for all tests. The strength of the relationships was described as detailed by Portney and Watkins, where 0.00-0.25 indicated little or no relationship; 0.26-0.50 indicated fair degree of relationship; 0.51-0.75 indicated moderate to good relationship, and 0.76-1.00 indicated good to excellent relationship.\textsuperscript{24}

RESULTS
There was no significant difference between the groups in age, weight, and height (p = 0.144, 0.584, 0.051) respectively, as shown in Table 1. The result of the MANOVA test showed significant differences regarding the measured core endurance tests between the healthy group and the nonspecific LBP group (p < 0.05). The athletes with nonspecific LBP group had significantly lower endurance test values when compared with the healthy control group.

Additionally, The MFS scores were statistically higher for the collegiate athletes with nonspecific LBP than those who had no LBP (p < 0.05). Outcomes are presented in Table 2. The relationship between MFS scores and each McGill's core endurance test for nonspecific LBP and normal healthy groups was calculated using Pearson correlation coefficient. No relationship was found between MFS scores and all McGill's core endurance test in the group without LBP. Good negative (r = -0.79) and moderate negative (r = -0.54) correlations were found between MFS and trunk extensor and flexor endurance tests, respectively, in the group with nonspecific LBP, as shown in Table 3.

DISCUSSION
The purpose of the present study was to test core muscular endurance in collegiate male athletes with and without nonspecific LBP and to correlate the results with their functional status as it is scored using MFS. According to the results of this study, the athletes in the LBP group showed significantly lower as compared to the group without LBP for core muscular endurance in the four tested directions. These findings should

**Table 2. McGill's core endurance test values and MFS scores of participants.**

<table>
<thead>
<tr>
<th></th>
<th>Athletes with LBP, n=30</th>
<th>Athletes without LBP, n=25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core endurance test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(seconds)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trunk flexor</td>
<td>43.76 ± 13.03</td>
<td>57.63±6.25</td>
</tr>
<tr>
<td>Trunk extensor</td>
<td>34.06 ± 9.44</td>
<td>63.20±11.57</td>
</tr>
<tr>
<td>Right lateral plank</td>
<td>28.74 ± 8.13</td>
<td>42.09±7.43</td>
</tr>
<tr>
<td>Left lateral plank</td>
<td>23.84 ± 7.05</td>
<td>33.90±8.16</td>
</tr>
<tr>
<td>MFS</td>
<td>46.98 ± 5.52</td>
<td>2.64 ± 3.40</td>
</tr>
</tbody>
</table>

MFS= Micheli Functional Scale, *Significant at p < 0.05

**Table 3. Correlation (r) between MFS and core endurance tests of athletes with and without nonspecific LBP.**

<table>
<thead>
<tr>
<th></th>
<th>Athletes with LBP (r)</th>
<th>Athletes without LBP (r)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFS</td>
<td>-0.54*</td>
<td>-0.13</td>
</tr>
<tr>
<td>Trunk flexor</td>
<td>-0.79*</td>
<td>-0.17</td>
</tr>
<tr>
<td>Trunk extensor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right lateral plank</td>
<td>-0.27</td>
<td>-0.07</td>
</tr>
<tr>
<td>Left lateral plank</td>
<td>-0.20</td>
<td>-0.04</td>
</tr>
</tbody>
</table>

LBP= Low back pain, MFS= Micheli Functional Scale, *Significant at p < 0.05
provide health care professionals with further into
trunk muscle performance in college aged athletes,
which could be integrated with the already existing
injury prevention program and rehabilitation proto-
cols for lumbar related athletic injuries. Many of these
injuries may be attributed to muscular deficiencies,
such as weakness and poor endurance.

Preparticipation physical examinations are often
performed as a major component of injury risk
reduction screens in order to identify potential risk
factors. Several activities have been identified as
potential screening tools, as standard procedure to
quantify trunk muscular endurance do not exist. In 1999, McGill et al. advocated the use of McGill’s
core endurance tests to evaluate the trunk muscu-
lature stamina especially in patients with LBP. Nor-
mative published data for the isometric endurance
of the trunk flexors and extensors using the ante-
orior and posterior (Sorensen) tests in novice athletes
with mean age 21 years are 136, and 161 seconds,
respectively. The mean endurance time for the right
and left lateral plank are 95, and 99 seconds. Of
note, the recorded scores for McGill’s core endur-
ance tests in all directions in the subjects in the cur-
rent study were markedly low for both groups as
compared with the international normative data.

The results of the present study are in accordance
with the findings of Sung, who reported increased
lumbar musculature fatigability in patients with
recurrent LBP, and with those of Da Silva et al. who
concluded that individuals with nonspecific LBP
presented with significantly more pronounced lum-
bar musculature fatigue via electromyography than
people without nonspecific LBP in both younger
and older adults. Moreover, the findings of Correia
et al. showed that symptomatic tennis players
with nonspecific LBP demonstrated lower activa-
tion of extensor muscles (erector spinae and longis-
simus thoracis), less co-contraction patterns and less
abdominal musculature endurance when compared
with the asymptomatic healthy players.

Additionally, the current study demonstrated that
lower times of McGill’s endurance test in the ante-
orior and posterior directions correlated with higher
scores on the MFS, indicating more difficulty in per-
forming athletic activities and higher pain in those
with poorer trunk endurance. The MFS was chosen
to assess pain and dysfunction in this study because
it is a back-specific rating scale for athletes at the
collegiate sports levels. It has been suggested that
athletes with poor trunk muscular endurance may
easily injure passive, pain-sensitive structures of the
lumbar spine, which ultimately affects physical per-
formance. Also, early loss of core control secondary
to fatigue may lead to aberrant or excessive interver-
tebrebral translation and rotational motion. Normal val-
ues for these osteokinematic movements have been
reported to be three to four millimeters translation
between L1 and S1 in the sagittal plane, seven to thir-
teen degrees for rotation in L1-L5 segments and 14-20
degrees in L5-S1. Local core muscles play an essen-
tial role in maintaining segmental stability and con-
trolling intervertebral motion. Kong et al. reported
that impairment of the function of these local mus-
cles in individuals with chronic nonspecific LBP can
change the extent of segmental vertebral motion.

During physical activities, the trunk musculature
provides both mobility and stability to the lumbo-
pelvic region. Changes in trunk muscle activity in
the form of weakness or insufficient motor control,
typicaly observed in individuals with LBP may
lead to increased dysfunction and suboptimal ath-
etic performance. Ambegaonkar et al. reported
that core musculature endurance test values did not
influence Star Excursion Balance Test (SEBT) scores.
Their results can be attributed to the muscular activ-
ation patterns of the knee, and various other leg
muscles during this specific functional test.

Laird et al. and Bystrom et al. concluded that core
stability exercises are more effective in reducing pain
and disability in the short, intermediate, and long
term compared to no treatment, regular medical
treatment, education, or general exercise in patients
with nonspecific LBP. A good negative correlation was
found between lumbar musculature endurance and
functional disability in the current study, which can
be attributed to the poor scores recorded specifically
in the posterior direction that were markedly lower
than those recorded in the control group and the ante-
orior direction of the same group. This demonstrated a
clear imbalance between the trunk flexors and exten-
sors when compared with the values reported in
other studies. No correlations were found between
right or left side endurance tests and MFS score. This
was most likely due to the nature of the activities of daily living listed in the questionnaire, which focused on pain associated with lumbar flexion, extension, and jumping, without including rotational or change of direction activities that requires the action of the oblique musculature.

There are some limitations of this study. First, this study was delimited to male collegiate athletes, thus limiting the generalizability of the results. Second, while McGill’s tests in four directions were used to assess the endurance of the prime movers of the core, other local stabilizers may have contributed to the outcomes on McGill’s tests (e.g. shoulder muscles to support the body during a plank position). Another limitation is the lack of correlating levels of the MFS scores to levels of sports disability as minimal, moderate, and severe. Further studies should identify the levels of sports disability with the MFS and relate this factor to core endurance. Such information may be helpful in the clinical decision-making surrounding return to competitive sports. Finally, more studies are needed to examine the effect of core stability training on trunk endurance in those with nonspecific LBP.

CONCLUSION
The results of this study demonstrated that collegiate athletes with nonspecific LBP had significantly lower trunk musculature endurance test values than healthy athletes. Good and moderate negative correlations were found between scores on the MFS and trunk extensor and flexor endurance tests, respectively. Therefore, the rehabilitation program of athletic population with nonspecific LBP should include strategies that emphasize endurance of the trunk extensors and flexors.

REFERENCES


ABSTRACT

Background. 48 percent of rowing injuries are due to overuse and occur more often in females. The Functional Movement Screen™ (FMS) is a screening tool utilized to identify the risk of musculoskeletal injury in field sport athletes based on movement patterns. It has not been used to identify risk of injury in rowing.

Objectives. The purpose of this study was to determine if the scores on the FMS™ are predictors of incidence of all injuries, including low back pain (LBP) in female collegiate rowers during one season of rowing.

Methods. Prospective cohort conducted in a clinical setting. Thirty-seven Division I female collegiate rowers (33 rowers and 4 coxswains). Investigators performed pre-season FMS™ screening and collected demographic data, rowing data, and Oswestry Low Back Pain questionnaire scores. Based on FMS™ scores, individuals were grouped high or low risk for injury. Injury reports and patient complaints of LBP over the course of a season were compared to FMS™ group.

Results. Those in the high risk group were significantly more likely to experience LBP during the season ($p = .036$) and reported a 58 percent greater mean in years of rowing experience ($p = .008$) than individuals in the low risk group. Those with a history of LBP were six times more likely to experience LBP during season ($p = .027$).

Discussion. The FMS™ indicated that rowers at a high risk of injury and more years of rowing experience, have a higher probability of sustaining LBP. Results could be due to chronic overuse associated with the rowing motion. Low back pain was evident in 25 out of the 37 participants over the season.

Conclusion. While the FMS™ has been proven to predict injury in field athletes, there was no statistically significant evidence to support prediction of a reported time loss injury in female collegiate rowers. However, it did indicate a higher likelihood for subjective report of low back pain.

Level of Evidence: Cohort study, level 2b

Key Words. Crew, injury risk, prevalence, women

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INTRODUCTION
Rowing injuries occur as a result of overuse and stress imposed on the body induced by the rowing stroke. In fact, rowing during practice and competition account for 48 percent of rowing injuries, with the remaining occurring during weight lifting and cross-training activities. Acute and chronic rowing injuries have been attributed to overuse, overload, and poor mechanics.

Low back pain (LBP) is one of the most common complaints among athletes, especially in sports that involve hyperextension, flexion and rotation. In the sport of rowing, spinal motion occurs in each of these three directions, increasing the risk of rowing athletes sustaining a low back injury. Fifteen to twenty-five percent of all rowing injuries are spinal injuries. Furthermore, 36 percent of competitive rowers with no recalled history of back pain prior to beginning the sport complained of developing LBP after training to row.

When comparing incidence of low back injury between sexes, females have an overall higher rate of injury compared to male rowers while training on the water with more than twice as many occurrences. Female rowers have an injury incidence rate of 51.28% as opposed to men with 21.98%. It has been suggested that this can be due to strength imbalances such as females’ quadriceps to hamstring ratio of 54-55% and other hip muscle imbalances. It may also be attributed to the subjective report of the threshold of pain between males and females. Twenty-four percent of females reported back pain compared to 21% of males, and women reported a greater severity of pain compared to men on the SF-36 bodily pain scale.

Asymmetries and compensations are important to recognize as they may be related to increased risk of injury. The Functional Movement Screen (FMS) is a screening tool administered and scored preferably by an FMS professional to identify the risk of musculoskeletal injury in individuals based on movement patterns. An FMS score of equal to or less than 14.3 ± 1.77 out of 21 was determined to indicate field sport athletes at a higher-risk for suffering a time loss injury. While the FMS has been considered to be a useful component of an athletic pre-participation exam, it has not been utilized or validated in the rowing population. The purpose of this study was to determine if the scores on the FMS are predictors of incidence of all injuries, and specifically low back pain, in female collegiate rowers during one season of rowing.

METHODS
Subjects
Forty-five Division I female collegiate rowers volunteered to participate in this institutional review board approved study. The inclusionary criteria included: female sex, current participation on a Division I collegiate rowing team, and being at least 18 years of age. The exclusionary factors for the potential subjects included use of a mobile or prophylactic device (e.g., shoulder or knee brace) or musculoskeletal and/or head injury occurrence in the six weeks prior to the start of the study. Participants reporting LBP in the six weeks prior to the study who were currently cleared for participation were included. Based on the regression analysis of three factors and p < .05, 45 participants were required to achieve a power of .80.

Instrumentation
The Oswestry Low Back Pain Questionnaire ([reliability Cronbach’s alpha: 0.71 to 0.87]) was used to assess pain-related restriction during day long activities. The questionnaire is a self-administered patient reported outcome that takes approximately five minutes to complete and has a maximum score of 50. There are 10 sections in the questionnaire, which have six answers choices for the addressed statement starting at low pain intensity progressing to high intensity. Each answer choice is delineated points of zero to five, respectively. The total score of the questionnaire determines the level of disability, revealing individuals with greater than or equal to 21 out of 50 as those experiencing symptoms of high disability.

A rowing specific questionnaire was constructed by the research team and was administered pre- and post-season. The data collected included demographics, years of rowing experience, rowing side (i.e., port or starboard), and LBP history prior to the current season. The participants completed the second section of the questionnaire post-season that
identified whether LBP was experienced within the season.

The FMS™ kit (Functional Movement Systems, Chatham, VA) is a pre-constructed apparatus utilized for completing the FMS™. The contents of this kit include a two inch by six inch board, three dowels (i.e., two short dowels and one four-foot long dowel), and an elastic cord which is assembled to evaluate seven different movement patterns without a warm up. Each movement is scored on a scale from zero to three. A score of zero indicates pain performing the movement, score of one means there is an inability to complete movement, score of two means that the subject can complete movement but with compensatory motions (e.g., muscular weakness, mobility constraints, or deviation from expected plane of movement), and a score of three indicates that the movement is performed fulfilling all required criteria. The maximum score achievable is 21. Each movement is performed barefoot with three trials and the best repetition is recorded. Intra-rater reliability was determined via data collected by the FMS™ Professional on five volunteer participants' FMS™ scores separated by one week. The FMS™ professional was blinded to the final scores until the end comparison was made. Intra-rater reliability was determined to be an ICC (3,1) of .87.

Data Collection Procedures

Each participant completed an informed consent and Health Insurance Portability and Accountability Act forms. Athletes who met inclusion criteria and were free from exclusionary factors moved into the testing phase. For pre-testing, the participant completed the Oswestry LBP Questionnaire and the first section of the rowing specific questionnaire. The study coordinator, a Board of Certification certified athletic trainer who is also certified in FMS™, conducted the full screening, scored and recorded according to the standard protocol prescribed by Functional Movement Systems™ (Functional Movement Systems, Chatham, VA).

Post-testing was completed at the end of the rowing season. Participants completed the Oswestry LBP Questionnaire and the post-season portion of the rowing specific questionnaire. Each participant’s FMS™ score was compared to the incidence of injury during the season. This information was collected from injury reports from the athletic trainer and official diagnosis from the team physician. An injury was defined as an incident that prevents the participant from practice for at least one day. However, if an athlete had a recurrent injury, only the first incident was recorded in the results.

Data Analysis

Data were analyzed with descriptive and inferential statistics using IBM SPSS 22.0 (p ≤ .05). Independent samples t-tests were used to identify FMS™ group differences in age, height, weight, years of rowing experience, total number of injuries, and general and low back injuries diagnosed by physician. Data were also analyzed using Chi-square statistics in order to determine significant associations between FMS™ group and history of LBP, history of other rowing injury, LBP during the season, low back injury during the season, other injury during the season, asymmetries detected in FMS™, and rowing position. Fisher’s Exact tests were used if any cells in the 2 x 2 contingency tables were less than 10. Sensitivity, specificity, and likelihood ratios were calculated when significant associations were identified between variables.

RESULTS

Means, standard deviations, and statistical analyses of participant demographic measurements by FMS™ group are presented in Table 1. There was a significant difference between high risk (FMS™ score of ≤14/21) and low risk (FMS™ score of ≥15/21) of injury groups in years of rowing experience. The high risk group had 58% greater years in rowing experience than the low risk FMS™ group. No other statistically significant differences were identified between high risk and low risk groups.

| Table 1. Subject demographic information by FMS™ group |
|-----------------------------------------------|-------------|-------------|-------------------------------|----------------|-------------|----------------|-------------|
| Demographics                                | M ± SD      | M ± SD      | Statistical Analysis t      | p             |             |
| Weight                                      | 152.88 ±20.11 | 152.07 ±19.65 | -0.102 .919 |             |             |
| Yrs of rowing                                | 4.88 ± 2.75  | 2.05 ± 2.43  | -2.83 .008*            |             |             |
| Age                                         | 19.25 ± 1.17 | 19.55 ± 1.21 | 0.628 .534            |             |             |
| Weight                                      | 66.50 ± 2.56  | 67.72 ± 3.31 | 0.967 .340            |             |             |

* Significant group difference (p ≤ .05). High risk group N = 9 and low risk group N = 29.
The association between FMS™ groups and low back pain throughout the season was analyzed using another contingency table (Table 2). Participants who were delineated as a high risk of injury by the FMS™ were more likely to suffer from LBP during the season \((p = .036)\).

To assess an association between FMS™ groups and post-season record of injuries, a contingency table was created (Table 3). There were no statistically significant findings. However, there were non-statistically significant trends of rate of injury per group. The high risk group had a 30% greater occurrence of injury compared to the low risk group.

A contingency table was created to assess an association between history of LBP and the development of LBP in the season (Table 4). Likelihood ratio sensitivity of history of LBP indicating LBP during the season was .48. Specificity of no history of LBP and not sustaining an injury was .92. Those participants with a history of LBP were six times more likely to experience LBP during season \((p = .027)\).

### DISCUSSION

In the current study, the FMS™ scores indicated that rowers and/or coxswains who were determined to be at a high risk of injury have a higher probability of sustaining LBP. Years of rowing was a factor in those participants who were at high risk of injury. This result could potentially be due to the repetitive rowing motion. Low back pain is prevalent in rowers regardless of the number of years of rowing and history of low back pain. Low back pain was self-reported by 25 out of the 37 participants over the season, indicating that 67.5% of participants did suffer pain but were not necessarily diagnosed with low back injury.

To attempt to explain the incidence of low back pain it is important to examine the biomechanics of the rowing motion. There is a purpose for the design of proper technique in any sport, but in rowing, a slight change in body angle or stroke sequence can significantly impact the joint positioning and stresses placed on the lower back. Bull et al conducted a study examining lumbosacral joint motion and hip flexion throughout rowing, which revealed that femoral flexion is reduced with fatigue and altered with poor rowing techniques. Ultimately fatigue may be the greatest contributor to excessive joint motion.18

In addition to noting different positions as rowers, a limited sample of four coxswains was also included. Although there were not any reportable statistically significant differences by position, three of the four coxswains experienced LBP. Additionally, two of the four coxswains were in the high risk of injury group. During long practices and races, coxswains are expected to stay in a very small space where they must remain as still as possible. While maintaining their stable body position, the coxswain will experience jarring of the boat with every stroke that is taken by the rowers. This position and the stabilization needed to combat the boat movement can cause neck and back pain to the coxswain. The type of boat and location of the coxswain seat will also determine the exact position in which they must sit. If the seat is in the bow of the boat, typically the coxswain will be in a lounged position with the legs extended. They must hold abdominal control at an angle in order to maintain a position where their sight is not impaired. If the seat is in the stern of the boat, the coxswain is expected to have flexed knees and hips while sitting in a hunched

<table>
<thead>
<tr>
<th>Table 2. FMS™ group versus LBP during season</th>
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<tbody>
<tr>
<td>FMS Group</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Low</td>
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<tr>
<td>High</td>
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<tr>
<td>Total</td>
</tr>
<tr>
<td>* Significant group difference ((p \leq .05)).</td>
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<table>
<thead>
<tr>
<th>Table 3. FMS™ group versus Injury Sustained during Season</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMS Group</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Low risk</td>
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<tr>
<td>High risk</td>
</tr>
<tr>
<td>Total</td>
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<tr>
<td>* Significant group difference ((p \leq .05)). High risk group N = 8</td>
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<table>
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<tr>
<th>Table 4. LBP during season versus History of LBP</th>
</tr>
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<tr>
<td>History of LBP</td>
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<tr>
<td></td>
</tr>
<tr>
<td>No</td>
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<tr>
<td>Yes</td>
</tr>
<tr>
<td>Total</td>
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<tr>
<td>* Significant group difference ((p \leq .05)).</td>
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</tbody>
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position in order to achieve the best aerodynamics of the boat. Either position can contribute to back pain.

The Oswestry Low Back Pain Questionnaire did not offer meaningful comparisons for this population of young, healthy, elite athletes. The Oswestry disability index results for these rowers was very low and had no variable change throughout season. This questionnaire does not appear to address the unique physical demands of a collegiate rowing population because the severity of disability the Oswestry questionnaire is assessing is likely more debilitating than an in season athletic injury may be. In order to assess this population on a more relatable level, a questionnaire should be designed to fit the rowing population in regards to the demands of training for the sport and the technique required.

This study was primarily focused on the FMS™ and its association with female rowers. For future studies, male rowers should also be analyzed to assess for differences in sex and also the effectiveness of FMS™ as a predictor of injury. Following that analysis, prescribing corrective exercises to each of the affected athletes would assess the FMS™ and its ability to prevent injury when used to determine treatment.

The FMS™ utilizes basic fundamental movement patterns which are useful in assessing compensatory movements in individuals. However, more specific evaluative patterns exist for different sports. Future direction for additional study could include developing sport specific screens to analyze those specific movements that could affect performance.

**CONCLUSION**

The Functional Movement Screen™ is not a sufficient predictor of reported time loss injury in female rowers but did predict incidence of LBP. Rowing utilizes very unique movement patterns as it requires multi-planar spinal movement performed in the seated position, which is not directly accounted for in the FMS™. Field sports have been proven to be more relatable to the patterns evaluated in the FMS™. Ultimately the most important clinical outcome would be to discover the most effective predictive instrument for identifying risk of injury. With an effective injury predictor in rowers, clinicians could identify those individuals at risk and incorporate individual prevention strategies.

**REFERENCES**

ABSTRACT

Background: Clinicians are interested in the foot strike pattern (FSP) in runners because of the suggested relationship between the strike pattern and lower extremity injury.

Purpose: The purpose of this study was to assess the ability of collegiate cross-country runners and recreational runners to self-report their foot strike pattern during running.

Study Design: Cross-sectional Study

Methods: Twenty-three collegiate cross-country and 23 recreational runners voluntarily consented to participate. Inclusion criteria included running at least 18 miles per week, experience running on a treadmill, no history of lower extremity congenital or traumatic deformity, or acute injury three months prior to the start of the study. All participants completed a pre-test survey to indicate their typical foot strike pattern during a training run (FSPSurvey). Prior to running, reflective markers were placed on the posterior midsole and the vamp of the running shoe. A high-speed camera was used to film each runner in standing and while running at his or her preferred speed on a treadmill. The angle between the vector formed by the two reflective markers and the superior surface of the treadmill was used to calculate the foot strike angle (FSA). To determine the foot strike pattern from the video data (FSPVideo), the static standing angle was subtracted from the FSA at initial contact of the shoe on the treadmill. In addition to descriptive statistics, percent agreement and Chi square analysis was used to determine distribution differences between the video analysis results and the survey.

Results: The results of the chi-square analysis on the distribution of the FSPSurvey in comparison to the FSPVideo were significantly different for both the XCRunners (p < .01; Chi-square = 8.77) and the REC Runners (p < .0002; Chi-square = 16.70). The cross-country and recreational runners could correctly self-identified their foot strike pattern 56.5% and 43.5% of the time, respectively.

Conclusion: The findings of this study suggest that the clinician cannot depend on an experienced runner to correctly self-identify their FSP. Clinicians interested in knowing the FSP of a runner should consider performing the two-dimensional video analysis described in this paper.

Level of Evidence: 3

Keywords: Foot strike, kinematics, running
INTRODUCTION
In the last several years, there has been an increased interest in the foot strike pattern in runners as a result of the suggested relationship between the strike pattern and lower extremity injury. The three common classifications of the pattern of foot strike during running are rearfoot, midfoot, and forefoot.1 A rearfoot strike pattern occurs when the heel or posterior aspect of the foot or shoe initially contacts the ground. A midfoot strike pattern occurs when the posterior and anterior portions of the foot or shoe contact the ground at the same time. A forefoot strike pattern occurs when the anterior part of the foot or shoe strikes the ground first. A recent systematic review assessing the biomechanical variations in foot strike patterns during running reported that rearfoot strikers have significantly higher vertical loading rates when initially contacting the ground in comparison to forefoot strikers when running with or without shoes.2 Several authors have reported that higher vertical impact forces during running may be a factor in the development of running-related injuries.3,4,5 In addition, Williams et al demonstrated that when running with shoes, a forefoot strike pattern resulted in a reduction of power absorption at both the hip and knee in comparison to rearfoot strikers when running with or without shoes.6 Several authors have reported that higher vertical impact forces during running may be a factor in the development of running-related injuries. In addition, Williams et al demonstrated that when running with shoes, a forefoot strike pattern resulted in a reduction of power absorption at both the hip and knee in comparison to rearfoot strike pattern. Thus, changing from a rearfoot to forefoot strike pattern could be an intervention strategy for a runner with a running-related hip or knee injury. Based on this information, it would appear to be important for the clinician to know the foot strike pattern as part of the physical examination of a runner with a running-related overuse injury. An important question is whether the clinician can depend on the runner to provide an accurate self-report of their foot strike pattern.

The ability of the runner to be able to accurately self-report their foot strike pattern was first reported on by Goss and Gross.7 These researchers conducted a retrospective study to determine the relationships between shoe type, foot strike pattern, and injury incidence in runners who reported running at least six miles per week. They reported that of the 904 runners who returned the survey 31% were rearfoot strikers, 43% were midfoot strikers, and 20% were forefoot strikers. In their paper, these authors indicated that they had tested 87 runners using an instrumented treadmill and that 69% of the runners could accurately self-report their own foot strike pattern. Unfortunately, no information regarding the methodology used to collect the foot strike data on these 87 runners was provided in the paper. In a more recent study, Goss et al assessed the accuracy of 60 healthy runners to self-report their foot strike pattern using an instrumented treadmill and 2-dimensional video assessment.8 The runners selected for this study had more than six months experience wearing traditional or minimalist footwear and ran a minimum of 12 miles per week. They found that only 41 runners (68.3%) accurately self-reported their foot strike patterns in comparison to the foot strike captured with the video recordings while running on the treadmill. While this study was the first to assess the ability of a runner to reliably self-report their foot strike pattern, a limitation of the research was the sampling speed of the video camera (60 Hz) as well as the method used to determine the runner’s foot strike pattern from the video recordings.

Although the traditional method for quantifying the foot strike pattern has been the strike index which is determined using a force platform, Goss et al classified the foot strike pattern from the video recordings based on visual observations by two experienced physical therapists. Unfortunately, Goss et al provided no information regarding the reliability of the visual observations by the two raters.8 The strike index, first reported by Cavanagh and LaFortune, is a measure of the location on the center of pressure line along the long axis of the foot based on the point of the runners initial contact with the force platform and is expressed as a percentage of total foot length.1 While the strike index is a very accurate method to determine the foot strike pattern, few clinics have access to force platforms. In attempt to determine the runners strike pattern without using a force platform, Altman and Davis described a kinematic method to calculate a foot strike angle that they compared to the strike index derived from a force platform.9 They reported that the foot strike angle, determined from video recordings of 20 shod runners obtained while running on a treadmill, was highly correlated with the strike index (R² = 0.85). These authors note that the foot strike angle can be easily done in the clinical setting on a treadmill using only a high-speed video camera and a simple angle extraction program.
Based on current research suggesting an association between the foot strike pattern and the potential for increased running-related injuries, the foot strike pattern of the runner would appear to be important information for the clinician as part of the examination process. Although the study by Goss et al has some limitations, based on these authors’ findings, the ability of the runner to accurately self-report their foot strike pattern is questionable. In addition, since Goss et al only included recreational runners in their study, the ability of runners involved in an organized team-based running program that requires greater weekly running mileage and provides consistent coaching could enhance the accuracy of the runner to self-report their foot strike pattern. Thus, the purpose of this study was to assess the ability of collegiate cross-country runners and recreational runners to self-report their foot strike pattern during running. The authors hypothesized that the collegiate cross-country runners would have a higher level of accuracy in predicting their foot strike pattern in comparison to the recreational runners because of greater weekly mileage and regular coaching.

**METHODS**

**Participant Characteristics**

Twenty-three Division II cross-country runners (XCRunners - 12 females and 11 males) and 23 experienced recreational runners (RECRunners - 9 females and 14 males) voluntarily consented to participate in this study. Participants were recruited from three local university Division II collegiate cross-country teams and the recreational runners were recruited from the Regis University population as well as the greater Denver, Colorado, metropolitan area through community advertisements and public information sessions. All runners selected for the study met the following inclusion criteria: (1) between the ages of 18 to 40 years; (2) ran at least 18 miles per week for one-year prior to participation in the study; (3) had previous experience running on a treadmill; (4) always utilized shoes when running; (5) no previous history of lower extremity congenital or traumatic deformity or previous surgery that resulted in altered bony alignment; and (6) no acute injury 3 months prior to the start of the study that led to inability to run at least 3 consecutive days during that time. The Institutional Review Board of Regis University approved the study protocol and all participants provided written informed consent prior to participation in the study.

**Procedures**

Upon arrival to the testing center, each participant’s height, weight, and blood pressure were recorded. The participants were then asked to complete a short running history survey which asked the average number of days they ran per week, the average number of miles they ran per week, and what they believed to be their typical foot strike pattern (FSPSurvey) would be during a training run. After completing the survey, each participant was asked to begin running on a treadmill for at least six minutes so that they could acclimate to the treadmill (Model Mercury S, Woodway USA Inc., Waukesha, WI 53186) used in the study as well as determine their preferred running speed for testing. Once the preferred running speed was selected and the participant indicated they were acclimated to the treadmill, the participant was asked to stand with equal weight on both feet while video data was recorded for static standing. Once static standing data was recorded, the participant was then asked to start running on the tread-
mill at his or her pre-selected running speed. Once
the subject indicated they were running comfortably
and what they thought was his or her typical running
style, they were asked to continue running for five
minutes while video data was recorded. All stand-
ing and running images were recorded using a high
speed camera (Model# EX FH25, Casio America Inc.,
Dover, NJ 07801) at a rate of 240 frames per second.

Data Analysis
For each participant, one static image and five
dynamic images for the right foot were captured from
the video recordings for analysis. The five dynamic
images captured at the point of initial shoe contact
with the treadmill were selected after three min-
utes from the start of video recording. Based on the
method described by Altman and Davis9 the angle
formed by the two reflective markers and the supe-
rior surface of the treadmill was used to calculate the
foot strike angle with the posterior shoe marker serv-
ing as the apex of the angle (Figure 2). A free-access
video analysis software program (Kinovea, version
0.8.15, http://www.kinovea.org) was then used to
calculate the FSA on all six images. To determine the
foot strike pattern from the video data (FSPVideo),
the static standing angle was subtracted from the
each of the five dynamic foot strike angles recorded
for the right foot at the point of initial contact of the
shoe with the treadmill while running. Based on the
criteria provided by Altman and Davis9, the FSPVideo
was classified as a rearfoot strike pattern if the foot
strike angle was greater than 8 degrees. If the foot
strike angle was between -1.6 and 8.0 degrees, the
FSPVideo was classified as a midfoot strike pattern.
If the foot strike angle was less than -1.6 degrees,
the FSPVideo was classified as a forefoot strike pat-
tern. For further statistical analysis, the mean of the
FSPVideo for the five running trials was utilized.

Statistical Analysis
In addition to descriptive statistics, percent agree-
ment was determined between the video analysis
results and the survey responses for foot strike angle.
Chi-square analysis was used to determine if differ-
ences existed in the distribution of self-reported foot
strike pattern responses in comparison to the FSA
between the XCRunners and the RECRunners. All
statistical analyses were performed using JMP soft-
An alpha level of .05 was established for all tests of
significance.

RESULTS
Demographic data for all subjects are listed in
Table 1. The distribution of the FSPSurvey and the
FSPVideo for the XCRunners and the RECRunners
are listed in Table 2 and 3, respectively. The majority
of the XCRunners ran on average six to seven times
each week, while the RECRunners ran on average
four to five times each week. The average number of
miles run for all participants was 39.6 miles with the
XCRunners and RECRunners averaging 54.1 and 25.0
miles per week, respectively. The results of the chi-
square analysis on the distribution of the FSPSurvey
in comparison to the FSPVideo were significantly dif-
ferent for both the XCRunners (p < .01; X² = 8.77)
and the REC Runners (p < .0002; X² = 16.70), indi-
cating for both groups a lack of agreement between

<p>| Table 1. Means (standard deviations) for participant demographics |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th></th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>BMI (kg/cm²)</th>
<th>Mileage per Week</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Runners</td>
<td>22.4 (5.6)</td>
<td>142.5 (22.3)</td>
<td>78.6 (4.6)</td>
<td>21.7 (1.8)</td>
<td>39.6 (18.2)</td>
</tr>
<tr>
<td>(n = 46)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recreational</td>
<td>29.3 (3.4)</td>
<td>147.3 (23.3)</td>
<td>78.4 (4.5)</td>
<td>22.2 (1.7)</td>
<td>25.0 (9.5)</td>
</tr>
<tr>
<td>Runners</td>
<td>(n = 23)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cross-Country</td>
<td>19.5 (51.1)</td>
<td>137.7 (20.8)</td>
<td>77.7 (4.8)</td>
<td>21.2 (1.9)</td>
<td>54.1 (12.1)</td>
</tr>
<tr>
<td>Runners</td>
<td>(n = 23)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. The foot strike angle formed by the two reflective
markers and the superior surface of the treadmill with the pos-
terior shoe marker the apex of the angle.
than the RECRunners. Even with this difference in training, the XCRunners in this study could correctly self-report their foot strike pattern 56.5% of the time in comparison to 43.5% for the RECRunners. As noted in Table 2, while the FSPVideo showed that 17 (74%) of the XCRunner group were rearfoot strikers, the FSP-Survey indicated that only 7 (30%) of the XCRunners self-reported they were a rearfoot striker. While the distribution of the XCRunners self-identified foot strike pattern was evenly distributed across all three strike patterns (7 rearfoot, 9 midfoot, 7 forefoot), the FSPSurvey indicated that 65% of the RECRunners self-reported that they were a midfoot striker. Similar to the XCRunners, the FSPVideo data showed that 83% of the RECRunners were rearfoot strikers.

The authors hypothesized that the collegiate cross-country runners would have a higher level of accuracy in predicting their foot strike pattern in comparison to the recreational runners because of greater weekly mileage and regular coaching. Based on the findings of the current study, even though the collegiate runners did run more miles per week and ran more frequently each week, there was only a 13% difference in the ability of the cross-country runners to self-report their foot strike pattern during running in comparison to the recreational runners. It is interesting to note that there were no significant differences in the FSPSurvey foot strike classification distribution between the collegiate and recreational runner groups with the midfoot strike pattern the most self-identified for both groups. Irrespective of the self-identified foot strike patterns for either running group, the result of the FSPVideo indicated that was no difference in the foot strike pattern distribution between the collegiate and recreational runners with the rearfoot strike pattern most prevalent in both groups. In light of these findings the authors failed to accept the proposed hypothesis. More importantly, the results of the current study indicate that the clinician cannot depend on an experienced runner to correctly self-report their foot strike pattern. Clinicians interested in knowing the foot strike pattern of a runner they are examining would need to consider utilizing a method similar to the one described in this paper.

The accuracy of the runners in the current study to self-report their foot strike pattern was lower than previously reported by Goss et al.8 One of the rea-

Table 2. Distribution of foot strike patterns from the questionnaire (FSPSurvey) and video analysis data (FSPVideo) for the cross-country runners

<table>
<thead>
<tr>
<th>Pattern</th>
<th>FSPSurvey</th>
<th>FSPVideo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rearfoot Strike</td>
<td>7</td>
<td>17</td>
</tr>
<tr>
<td>Midfoot Strike</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Forefoot Strike</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Chi Square statistic = 8.77, p &lt; .012</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Distribution of foot strike patterns from the questionnaire (FSPSurvey) and video analysis data (FSPVideo) for the recreational runners

<table>
<thead>
<tr>
<th>Pattern</th>
<th>FSPSurvey</th>
<th>FSPVideo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rearfoot Strike</td>
<td>6</td>
<td>19</td>
</tr>
<tr>
<td>Midfoot Strike</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>Forefoot Strike</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Chi Square statistic = 16.70; p &lt; .0002</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

their perceived and actual strike pattern. The chi-square analysis for the distribution of the FSPSurvey responses for the XCRunners in comparison to the RECRunners was not significantly different (p = .113; X² = 4.35). The chi-square analysis for the FSPVideo classification distribution between the XCRunners and RECRunners was also not significantly different (p = .77; X² = 0.51). The XCRunners correctly self-identified their foot strike pattern 56.5% of the time, whereas the RECRunners could only correctly self-identified their foot strike pattern 43.5% of the time.

**DISCUSSION**

The intent of this study was to assess the ability of collegiate cross-country runners in comparison to recreational runners to self-report their foot strike pattern during running. Previous authors have reported that recreational runners can self-identify their foot strike pattern in running approximately 68% of the time.8 In their study, the accuracy of the runners ability to self-report their foot strike pattern was assessed using visual observations by two experienced physical therapists to classify foot strike patterns rather than the traditional method of using a force platform to determine the strike index. In addition, this study only assessed recreational runners and did not include runners involved in an organized team-based running program.8

Even though none of the RECRunners who participated in this study ran less than 18 miles per week, as expected the XCRunners ran almost twice as many miles per week and ran more frequently each week than the RECRunners. Even with this difference in training, the XCRunners in this study could correctly self-report their foot strike pattern 56.5% of the time in comparison to 43.5% for the RECRunners. As noted in Table 2, while the FSPVideo showed that 17 (74%) of the XCRunner group were rearfoot strikers, the FSP-Survey indicated that only 7 (30%) of the XCRunners self-reported they were a rearfoot striker. While the distribution of the XCRunners self-identified foot strike pattern was evenly distributed across all three strike patterns (7 rearfoot, 9 midfoot, 7 forefoot), the FSPSurvey indicated that 65% of the RECRunners self-reported that they were a midfoot striker. Similar to the XCRunners, the FSPVideo data showed that 83% of the RECRunners were rearfoot strikers.

The authors hypothesized that the collegiate cross-country runners would have a higher level of accuracy in predicting their foot strike pattern in comparison to the recreational runners because of greater weekly mileage and regular coaching. Based on the findings of the current study, even though the collegiate runners did run more miles per week and ran more frequently each week, there was only a 13% difference in the ability of the cross-country runners to self-report their foot strike pattern during running in comparison to the recreational runners. It is interesting to note that there were no significant differences in the FSPSurvey foot strike classification distribution between the collegiate and recreational runner groups with the midfoot strike pattern the most self-identified for both groups. Irrespective of the self-identified foot strike patterns for either running group, the result of the FSPVideo indicated that was no difference in the foot strike pattern distribution between the collegiate and recreational runners with the rearfoot strike pattern most prevalent in both groups. In light of these findings the authors failed to accept the proposed hypothesis. More importantly, the results of the current study indicate that the clinician cannot depend on an experienced runner to correctly self-report their foot strike pattern. Clinicians interested in knowing the foot strike pattern of a runner they are examining would need to consider utilizing a method similar to the one described in this paper.

The accuracy of the runners in the current study to self-report their foot strike pattern was lower than previously reported by Goss et al.8 One of the rea-
A limitation of this study was that the participant's foot strike pattern was assessed while running on a treadmill instead of while running overground. To enhance the clinical applicability of the current study, the authors utilized a treadmill to perform the running analysis since a treadmill would be commonly used in the typical clinical setting. Several authors have reported that the use of a treadmill when performing a running analysis can cause alterations in the pattern of lower extremity movement as well as ground reaction forces. In one of the only studies to compare overground versus treadmill running kinematics and kinetics using a force-transducer instrumented treadmill, Riley et al reported that a treadmill-based analysis of running mechanics can be generalized to overground running mechanics, provided the running speed on the treadmill is similar to individuals overground running speed. The fact that the authors of the current study only assessed the foot strike pattern for the right foot for each participant could also be considered a limitation. Although only the right foot was analyzed, the strike pattern for both feet of each runner was visually assessed to ensure they were similar.

CONCLUSION
While the etiology of running-related overuse injuries have been shown to be multifactorial, knowledge of the foot strike pattern would appear to be important information for the clinician managing a runner with running-related overuse injury. The results of this study substantiate the findings of previous research demonstrating that the ability of collegiate or recreational runners to accurately self-report their foot strike pattern is poor. If the clinician is interested in understanding the foot strike pattern of a runner as part of their physical examination, the methodology described in this paper can be easily performed in the clinical setting using a treadmill, a low cost high-speed camera, and a simple computer-based angle extraction program.

REFERENCES
ABSTRACT

Background: The mSEBT is a screening tool used to evaluate dynamic balance. Most research investigating measurement properties focused on intrarater reliability and was done in small samples. To know whether the mSEBT is useful to discriminate dynamic balance between persons and to evaluate changes in dynamic balance, more research into intra- and interrater reliability and smallest detectable change (synonymous with minimal detectable change) is needed.

Purpose: To estimate intra- and interrater reliability and smallest detectable change of the mSEBT in adults at risk for ankle sprain.

Study Design: Cross-sectional, test-retest design

Methods: Fifty-five healthy young adults participating in sports at risk for ankle sprain participated (mean ± SD age, 24.0 ± 2.9 years). Each participant performed three test sessions within one hour and was rated by two physical therapists (session 1, rater 1; session 2, rater 2; session 3, rater 1). Participants and raters were blinded for previous measurements. Normalized composite and reach direction scores for the right and left leg were collected. Analysis of variance was used to calculate intraclass correlation coefficient values for intra- and interrater reliability. Smallest detectable change values were calculated based on the standard error of measurement.

Results: Intra- and interrater reliability for both legs was good to excellent (intraclass correlation coefficient ranging from 0.87 to 0.94). The intrarater smallest detectable change for the composite score of the right leg was 7.2% and for the left 6.2%. The interrater smallest detectable change for the composite score of the right leg was 6.9% and for the left 5.0%.

Conclusion: The mSEBT is a reliable measurement instrument to discriminate dynamic balance between persons. Most smallest detectable change values of the mSEBT appear to be large. More research is needed to investigate if the mSEBT is usable for evaluative purposes.

Level of Evidence: Level 2

Keywords: Ankle, Dynamic Balance; mSEBT; Reliability; smallest detectable change

CORRESPONDING AUTHOR

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BACKGROUND
Ankle sprains are common in young adults, participating in competitive, court and team sports such as soccer, volleyball, tennis, hockey and running.1,2 Patients with ankle sprains suffer from pain, limitations in activities and participation restrictions, resulting in high costs for individual sport participants and society.1,3-5 Considering the impact of ankle sprains, injury prevention is important in sports. Dynamic balance deficits, defined as limitations in the ability to hold a stable base of support while making purposeful movements like reaching,6 are related to an increased risk for ankle sprain.7-11 For the development of effective prevention programs, a screening tool to detect and evaluate persons with dynamic balance deficits is needed.

The modified Star Excursion Balance Test (mSEBT) is a screening tool, widely used by physical therapists to detect dynamic balance deficits, and to evaluate dynamic balance improvement in individuals after following a preventive training program.7,12-15 The mSEBT measures dynamic balance, while a person maintains balance on a single leg and simultaneously reaches as far as possible with the other leg along the reach line of three directions (anterior, posteromedial and posterolateral). Originally composite scores (sum scores of the three directions) of the mSEBT were used as an index for dynamic balance. Recently, there is emerging evidence that specific reach directions of the mSEBT correlate with some specific lower extremity impairments.7,16-18 Therefore, scores of separate reach directions as well as composite score are used as indices of dynamic balance.

To determine whether the mSEBT is a reliable measurement instrument to evaluate individual dynamic balance performance, insight into measurement properties of the test is necessary. For diagnostic purposes reliability (the degree until which the mSEBT can differentiate balance performances between persons) is an important parameter. For evaluative purposes, information about measurement error and the minimal amount of change above measurement error (smallest detectable change synonymous with minimal detectable change) is needed to know whether changes in performance should be attributed to measurement error or to true changes in performance.19 In the current study reliability, measurement error and smallest detectable change (SDC) are referred to under the umbrella term reproducibility. For practitioners and researchers it is important to gain insight in reproducibility of the mSEBT under several conditions. Namely, when the mSEBT is used by different raters (interrater), and by the same raters (intrarater) on different occasions. Intra- and interrater reliability of the mSEBT were investigated in different studies and seem to be good to excellent.6,20-24 However, commonly identified flaws in these studies were small sample sizes, absence of a clear measurement protocol or missing information regarding measurement error and SDC values. Information about intra- and interrater reproducibility, based on high quality studies is needed to confirm intra- and interrater reliability of the mSEBT and to investigate whether the mSEBT is useful to evaluate changes in performance in persons at risk for ankle sprain over time. Therefore the aim of the current study is to estimate the intra- and interrater reproducibility in healthy young adults participating in sports at risk for ankle sprain.

METHODS
Participant characteristics
A convenience sample of volunteers was recruited in the Netherlands at Utrecht School of Medicine, University Medical Center Utrecht, Utrecht University; and at University of Applied Sciences Utrecht; and from researchers’ personal networks. Students and workers from Utrecht School of Medicine and University of Applied Sciences Utrecht were informed about this research and asked to participate via e-mail, and their digital learning environment. Furthermore, friends and colleagues of the researchers were informed about the research and asked to participate. Included were healthy persons between 18 and 30 years old who participated at least once a week in a selection of sports with increased risk for ankle sprain. Based on the number of ankle injuries treated in emergency departments, the following sports were defined as sports with increased risk for ankle sprain: running, soccer, volleyball, futsal, hockey, badminton, tennis, martial arts, handball, squash, gymnastics, korfball, basketball.25 Excluded were persons who reported lower extremity injury within the past twelve months, cerebral concussion within the previous three months, history of prior ankle surgery, and history of neurological disorders affecting balance.
Participant characteristics such as age, gender, dominant leg (preferred kicking leg), history of ankle sprain, participation in sports with increased risk for ankle sprain and sport frequency were collected. The study was approved by the University Medical Center Utrecht Medical Ethics Committee, METC-protocol number 13-156/C. Informed written consent was obtained from all subjects prior to participation in the study and the rights of the subjects were protected throughout the study.

**Rater characteristics**

Four physical therapists were randomly chosen from a group of 10 physical therapists that participated in the master program Physical Therapy Science at University Medical Centre Utrecht and were selected by convenience sampling. The chosen physical therapists were trained during two standardization sessions, each session took two hours. During the standardization sessions a specifically developed measurement protocol was discussed and practiced. This protocol also included verbal instructions (test instructions and encouragements) given to the participant.

**Measurement procedure and protocol mSEBT**

A cross-sectional, test-retest design (rater 1, rater 2, rater 1) was used to examine the intra- and inter-rater reproducibility of the mSEBT (Figure 1). The four raters were rotated in two couples of two raters with one test couple simultaneously measuring two participants (Figure 1). Each participant performed three test sessions by two raters (session 1, rater 1; session 2, rater 2; session 3, rater 1) within one hour. To ensure blinding of raters for previous measurement, forms with the recorded data were collected after each test session (by a research assistant). In order to prevent missing items all data were checked by a research assistant before participants left the test location.

![Figure 1. Study design used to investigate reproducibility of the mSEBT](image-url)
Before testing was started, participants viewed an instructional video, which demonstrated the test and the testing procedure, followed by four practice trials in each of the three reach directions on each leg. Participants performed the mSEBT standing at the center of a grid laid on the floor with three reach lines in the form of an Y. The three reach lines were labeled in relation to the stance leg as anterior (A), posteromedial (PM) and posterolateral (PL) directions, with two angles of 135° (between the A and PM line and between the A and PL line) and one angle of 90° (between the PM and PL line) (Figure 2). The lines were constructed with standard tape measures and transparent tape on the floor. For the anterior reach direction participants were standing with the most distal part of the big toe at the cross of the Y at the beginning of the anterior tape measure. For the posterior reach directions participants were standing with the most posterior part of the heel at the cross of the Y at the beginning of the anterior tape measure. Participants were barefooted and asked to place both hands on the hips. Participants were instructed to reach as far as possible along each of the three reach lines, make a light touch on the line with the most distal part of the big toe and return the reaching leg back to the center while maintaining a single-leg stance with the other leg. Participants performed three trials in each direction on each leg. The test started with the right leg as stance leg followed by the left leg in successively the A, PM and PL reach directions. Ten seconds of rest were provided between the different trials of one reach direction. A trial was discarded and repeated if participants (1) took weight on the reaching foot; (2) failed to bring back the reaching foot to the starting position without losing control; (3) failed to keep both hands on hips; (4) failed to keep the stance foot at the same place; or (5) failed to keep the forefoot or heel of the stance foot on the floor.6,23,26 A maximum of six attempts per reach direction was allowed to obtain three valid scores. The three valid scores were averaged and used to calculate normalized mSEBT scores. The rater recorded scores of each trial in each reach direction in centimeters.

Calculating normalized mSEBT scores
To normalize reach distances the participant's leg length was measured from the anterior superior iliac spine to the distal tip of the medial malleolus with the participant lying supine.26,27 Right and left leg length were measured two times and averaged. A standard tape measure was used to quantify the distance in centimeters.

For each reach direction, the mean out of the scores of three trials was calculated and normalized. Normalization was accomplished by dividing the mean reach distance by the participants (stance) leg length and then multiplying by 100%.27 In order to calculate a composite score, the mean of the three normalized reach direction scores was calculated.
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Data analysis

According to the recommendations of the COnsensus-based Standards for the selection of health Measurement INstruments (COSMIN) group and a sample size calculation as described by Giraudet and Mary, at least 50 participants should be included in the study.28,29 The COSMIN initiative aims to improve the selection of health measurement instruments. As part of this initiative, the COSMIN group developed a critical appraisal tool (a checklist) containing standards for evaluating the methodological quality of studies on the measurement properties of health measurement instruments (http://www.cosmin.nl).

Descriptive statistics including frequencies, percentages, means, and standard deviations were used to describe the research population. Measurement properties (intra- and interrater reliability, measurement error and SDC values) were estimated according to the recommended methods of the COSMIN group.30

RESULTS

Participant characteristics

Sixty-six adults between the ages of 18 to 30 years signed up to participate. Nine did not meet the inclusion criteria and two did not show up. Therefore, 55 participants (62% female) were included in this study, with a mean age of 24.0 (SD 2.9) years; a mean leg length of 90.9 (SD 6.4) cm, and quarter of participants had a history of ankle sprain. Participants performed sports with an increased risk for ankle sprain on average 2.3 (SD 1.2) times a week. See Table 1 for participant characteristics.

Intrarater and interrater reliability and agreement parameters were assessed on 55 pairs of observations by four physical therapists (3 males, working experience ranged from six months to 11 years). Missing data was below 2%. Therefore, no further actions were taken and available data were analyzed.

Reliability

Reliability was assessed with the intraclass correlation coefficient (ICC). Analysis of variance was used to calculate ICC consistency (model 3.1) for intrarater reliability, and ICC agreement (model 2.1) for interrater reliability.19,31,32 Interpretation of ICC scores was as following: Poor reliability ICC < 0.40, Fair reliability ICC 0.40 - 0.70, Good reliability ICC 0.70 – 0.90 and Excellent reliability ICC > 0.90.33

Measurement error

Measurement error (intra- and interrater agreement) was investigated calculating Bland and Altman 95% limits of agreement (LoA). LoA illustrates the range and magnitude of the differences in measurements between or within raters.34

Smallest detectable change

SDC refers to the smallest amount of change, which falls outside the measurement error of the measurement instrument.19 To calculate SDC values, first intra- and interrater measurement error were expressed in the units of measurement error: standard error of measurement agreement (SEM agreement). Analysis of variance was used to calculate SEM agreement.19,31 SDC was based on SEM and calculated using the following formula: SDC = 1.96*2*SEM.19

All statistical analyses were performed using SPSS version 20 (SPSS Inc., Chicago, IL). All data entry was double checked by another researcher. In case of missing data, no further actions were taken and available data were analyzed when missing data remains below 5%.

Table 1. Participant characteristics (N = 55)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Men / Female, n/n (%/%)</th>
<th>Age (y), mean (SD)</th>
<th>Right/left leg length (cm), mean (SD)</th>
<th>Dominant leg right / dominant leg left, n/n (%/%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>History of ankle sprain, n (%)</td>
<td>21/34 (38/62)</td>
<td>24.0 (2.9)</td>
<td>90.9 (6.3)/ 90.9 (6.4)</td>
<td>51/4 (92.7/7.3)</td>
</tr>
<tr>
<td>Weekly frequency participation in risk sports, mean (SD)</td>
<td>2.3 (1.2)</td>
<td></td>
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<tr>
<td>Participation in risk sports, n (%)</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Running</td>
<td>36 (65)</td>
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<tr>
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<td>Martial arts</td>
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<td>2 (4)</td>
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<tr>
<td>Squash</td>
<td>2 (4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gymnastics</td>
<td>1 (2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Korfball</td>
<td>1 (2)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Interrater reliability for the right leg was good to excellent (ICC values ranged from 0.87 (PM and PL) to 0.92 (A)). For the left leg excellent interrater reliability was found for all separate direction scores as well as the composite score (ICC values ranged from 0.92 (PL) to 0.94 (Composite)) (See Table 2).

**Measurement error**

Intrarater LoA for the composite score of the right leg demonstrated a mean difference in normalized scores within raters of -1.4%. For the left leg the mean difference in composite score within raters was -1.6% (See Table 3).

Interrater LoA for the right leg demonstrated a mean difference between raters for the composite scores of -0.3%. For the left leg the mean difference in composite scores between raters was -2.8% (See Table 3).

**Smallest detectable change**

Intrarater SDC values for the right leg ranged from 4.7% (A) to 12.7% (PL) and the value for the composite score of the right leg was 7.2%. Intrarater SDC values for the left leg ranged from 1.8% (A) to 10.8% (PL) and the SDC value for the composite score of the left leg was 6.2%.

Intrarater SDC values for the right leg ranged from 4.4% (A) to 12.3% (PL) and the SDC value for the composite score of the right leg was 6.9%.

### Table 2. Intra- and interrater reliability and agreement for composite and separate reach direction scores of the mSEBT (N = 55)

<table>
<thead>
<tr>
<th>Direction</th>
<th>Mean (SD)</th>
<th>Intrarater</th>
<th></th>
<th>Inter rater</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ICC&lt;sup&gt;+&lt;/sup&gt;</td>
<td>SEM Agreement</td>
<td>SDC Agreement</td>
<td>ICC&lt;sup&gt;+&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Consistency</td>
<td></td>
<td></td>
<td>Agreement</td>
</tr>
<tr>
<td>Right leg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Composite score</td>
<td>72.3 (2.9)</td>
<td>0.91</td>
<td>2.6</td>
<td>7.2</td>
<td>0.91</td>
</tr>
<tr>
<td>Anterior</td>
<td>65.3 (5.4)</td>
<td>0.91</td>
<td>1.7</td>
<td>4.7</td>
<td>0.92</td>
</tr>
<tr>
<td>Posteromedial</td>
<td>78.0 (9.6)</td>
<td>0.87</td>
<td>3.9</td>
<td>10.7</td>
<td>0.87</td>
</tr>
<tr>
<td>Posterolateral</td>
<td>73.6 (11.7)</td>
<td>0.87</td>
<td>4.6</td>
<td>12.7</td>
<td>0.87</td>
</tr>
<tr>
<td>Left leg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Composite score</td>
<td>73.0 (7.3)</td>
<td>0.93</td>
<td>2.2</td>
<td>6.2</td>
<td>0.94</td>
</tr>
<tr>
<td>Anterior</td>
<td>66.0 (5.4)</td>
<td>0.89</td>
<td>0.7</td>
<td>1.8</td>
<td>0.93</td>
</tr>
<tr>
<td>Posteromedial</td>
<td>80.0 (8.8)</td>
<td>0.90</td>
<td>3.0</td>
<td>8.4</td>
<td>0.93</td>
</tr>
<tr>
<td>Posterolateral</td>
<td>73.1 (10.8)</td>
<td>0.91</td>
<td>3.9</td>
<td>10.8</td>
<td>0.92</td>
</tr>
</tbody>
</table>

<sup>*</sup>All values except ICC are normalized excursion reach distance (reach distance / leg length x 100%).

### Table 3. Mean differences in normalized reach direction scores and 95% limits of agreement within and between raters

<table>
<thead>
<tr>
<th>Direction</th>
<th>Mean (SD)</th>
<th>Intrarater</th>
<th></th>
<th>Inter rater</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean difference within raters</td>
<td>Upper bound of 95% LoA</td>
<td>Lower bound of 95% LoA</td>
<td>Mean difference between raters</td>
</tr>
<tr>
<td>Right leg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Composite score</td>
<td>72.3 (2.9)</td>
<td>-1.4</td>
<td>5.4</td>
<td>-8.1</td>
<td>-0.3</td>
</tr>
<tr>
<td>Anterior</td>
<td>65.3 (5.4)</td>
<td>-0.2</td>
<td>4.5</td>
<td>-5.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Posteromedial</td>
<td>78.0 (9.6)</td>
<td>-2.0</td>
<td>8.0</td>
<td>-12.0</td>
<td>-0.4</td>
</tr>
<tr>
<td>Posterolateral</td>
<td>73.6 (11.7)</td>
<td>-2.1</td>
<td>10.0</td>
<td>-14.2</td>
<td>-5.0</td>
</tr>
<tr>
<td>Left leg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Composite score</td>
<td>73.0 (7.3)</td>
<td>-1.6</td>
<td>3.8</td>
<td>-7.0</td>
<td>-2.8</td>
</tr>
<tr>
<td>Anterior</td>
<td>66.0 (5.4)</td>
<td>-0.2</td>
<td>5.0</td>
<td>-5.4</td>
<td>-0.2</td>
</tr>
<tr>
<td>Posteromedial</td>
<td>80.0 (8.8)</td>
<td>-1.6</td>
<td>6.3</td>
<td>-9.5</td>
<td>-1.6</td>
</tr>
<tr>
<td>Posterolateral</td>
<td>73.1 (10.8)</td>
<td>-2.8</td>
<td>6.5</td>
<td>-12.2</td>
<td>-2.8</td>
</tr>
</tbody>
</table>

LoA = limits of agreement
SDC values for the left leg ranged from 4.4% (A) to 9.0% (PL) and the interrater SDC value for the composite score of the left leg was 5.0%. See Table 2 for all SDC values for the mSEBT.

**DISCUSSION**

In the current study, intra- and interrater reproducibility of the mSEBT were investigated in a sufficiently large sample of 55 healthy young adults participating in sports at risk for ankle sprain. The results show that the mSEBT has good to excellent intra- and interrater reliability despite the large variation in work experience (from 6 months to 11 years) between the four trained physical therapists who administered the test. Therefore, the current study results suggest that anyone can administer the test if trained properly. SDC values for the composite scores appear to be quite large. Changes in normalized composite scores of at least 6.9% for the right leg and 5.0% for the left leg are needed to observe a true change in performance of dynamic balance.

Earlier studies investigating reliability of the mSEBT gave indications that the mSEBT is a reliable measurement instrument. However, these studies did not fully accomplish current methodological recommendations for clinimetric research as described in the COSMIN standard. Other authors used small sample sizes or a poor description of the used measurement procedures. The current study performed according to the COSMIN standard, sufficiently powered, and used a transparent measurement protocol according to the recommendations of Gribble and Plisky, confirmed that the mSEBT is a reliable measurement instrument. Recapitulating, the results of the current study support previous findings, that the mSEBT is a reliable measurement instrument, which can be used in practice by one or more raters.

Questions arise whether the found SDC values are acceptable and the mSEBT is an appropriate tool to evaluate dynamic balance performance and risk for ankle sprain in individuals. SDC values for composite reach directions seem to be large and therefore small changes on the mSEBT might occur due to measurement error instead of actual improvement in dynamic balance. Currently, there is no research studying the required minimal improvement in dynamic balance to decrease risk for ankle sprain. To draw conclusions whether the mSEBT is usable tool for evaluative purposes, further research is needed to investigate the required minimal clinically important difference.

It should be noted that the reach distances obtained in the current study are relatively low compared to normative data from healthy subjects in earlier research. In other studies the PM reach direction scores are close to 90% or 100% from leg length, where the scores in the current study and the study of McCann are around 80% of leg length. The differences in reach distance scores compared with earlier results could be explained by several reasons. First, the population in our study is not completely comparable to the populations in the previous studies. In the current study, a large proportion of female participants, of recreational activity level, and mostly active in running participated, which may have resulted in relatively low reach distance scores. Second, differences in calculations and protocols used in the studies may have resulted in lower reach distance scores compared to previous studies. In the current study the average score was used for calculation, while in some other studies the highest score out of three trials was used. The protocol used in the current study was a very strict protocol (e.g. both hands had to stay on the hips, forefoot and heel had to keep contact with the floor and start position of the great toe and heel at the beginning of the tape) where other studies handled a less stringent protocol. Moreover, the current authors also looked into whether fatigue could have affected the observed reach distances. None of the participants reported fatigue symptoms during the test sessions and post hoc analyses on the composite scores of the left and right leg showed no significant differences in composite scores between the different sessions. This indicates that the mSEBT performance was stable across the test sessions and there were no signs of a deterioration of performance due to fatigue within the hour testing.

In the current study, injury risk stratification based on the cut-off points found by Plisky et al. and Butler et al. does not seem useful. Plisky found that in high school female basketball players athletes with a composite reach distance less than 94.0% leg length were 6.5 times more likely to have a lower extrem-
ity injury including ankle sprains. Butler reported that male college football players who scored below 89.6% leg length were 3.5 times more likely to get injured. However, risk stratification based on these cut-off points seems not plausible because almost all participants in the current study performed below the cut-off points and it is not likely that all of them had an elevated risk for lower extremity injuries. As earlier mentioned an important explanation for the lower test scores in the current study are the differences between the study populations. As suggested by Butler et al. there is need for developing population-specific cut-off points to screen athletes for injury risk.

A remarkable finding of the current study is that SDC values for the left leg are systematically lower than SDC values for the right leg. A possible explanation for the difference in SDC values could be the effect of cross-education. Earlier research has shown that unilateral balance training was effective in improving neuromuscular reactions to perturbations during single-leg stance for the trained but also for the untrained leg. In the current study each test was started with the right leg as the stance leg and therefore a cross-education effect due to training of the right stance leg may have caused a more stable performance of the leg. Furthermore, it could be hypothesized that because of right feet dominance in the study population (right leg dominance in 51 out of 55 participants) the left leg is mostly the stance leg during balance tasks and therefore is more trained in dynamic balance. This could have led to a more stable performance in maintaining balance for the left leg, resulting in lower SDC values. Although, previous studies do not show differences in mean scores for dynamic balance between the dominant and non-dominant leg, no research has investigated differences in measurement error between the dominant and non-dominant leg. In summary, it is unclear whether the differences in SDC values between the left and right leg found in the current study should be attributed to the test sequence used in the measurement protocol or to differences between the dominant and non-dominant leg.

It should be noted that in the current measurement protocol the leg length test was part of the evaluation of the mSEBT. The leg length test is a potential contributor to measurement error. In our study protocol the raters measured the participant's leg length in each of the three test sessions. Since the mSEBT is used in practice to evaluate change in dynamic balance an investigator is not interested in change in leg length. Therefore, measuring leg length at baseline and using these values across the successive tests would be more efficient and decreases the measurement error between mSEBT measurements. Nevertheless, post hoc analyses on measurement error of the leg length measurements showed only a minor contribution to measurement errors. In the current sample inter-rater (average) leg length SEM agreement values were respectively 0.90cm and 0.93cm for the right and the left leg and for both legs ICC values for inter-rater reliability were higher than 0.99. Looking at intra-rater (average) leg length, SEM consistency values were respectively 0.46cm and 0.43cm for the right and the left leg and for both legs inter-rater reliability ICC values were 0.98.

When interpreting the data it has to be taken into account that the SDC values investigated in the current study are based on a sample of healthy young adults participating in sports with increased risk for ankle sprain. SDC values are population specific and may be different in a population suffering from ankle or other lower extremity injuries. Therefore, the authors recommend that future research should study the measurement properties of the mSEBT using the same measurement protocol but in different populations at risk for lower extremity injuries and in populations suffering from different lower extremity injuries. Another consideration is that since each test was started with the right leg, the possible influence of a cross education effect could not have been ruled out. The authors therefore recommend that future research should focus on the influence of possible cross education effects, and on side to side differences in measurement error and SDC values, when using a controlled test order.

CONCLUSION

The mSEBT is a reliable measurement instrument used to discriminate dynamic balance between healthy young adults, participating in sports with increased risk for ankle sprain. For evaluative purposes changes of the composite score of at least 6.9% and 5.0% for the right stance leg and the left
stance leg respectively are needed to feel confident that real improvement has occurred in an individual’s dynamic balance. More research is needed to investigate if the mSEBT is usable for evaluative purposes of individual dynamic balance, and whether differences in SDC values are due to leg dominance or cross education effect.

REFERENCES


ABSTRACT

Background: Injury has been linked with altered postural control in active populations. The association between running injury and dynamic postural control has not been examined.

Hypothesis/Purpose: The purpose of this study was to examine dynamic postural control in injured and uninjured runners using the Star Excursion Balance Test (SEBT), Time to Stabilization (TTS) of ground reaction forces following a single-leg landing, and postural stability indices reflecting the fluctuations in GRFs during single-leg landing and stabilization tasks (forward and lateral hop). It was hypothesized that dynamic postural control differences would exist between runners with a history of injury that interrupted training for ≥7 days (INJ) when compared to runners without injury (CON).

Design: Case-control study

Methods: Twenty-two INJ (14 F, 8 M; 23.7±2.1 y; 22.3±2.8 kg/m2; 29.5±16.3 mi/wk) currently running >50% pre-injury mileage without pain were compared with twenty-two matched CON (14 F, 8 M; 22.7±1.2 y; 22.7±2.7 kg/m2; 31.2±19.6 mi/wk). INJ group was stratified by site of injury into two groups (Hip/Thigh/Knee and Lower Leg/Ankle/Foot) for secondary analysis. Leg length-normalized anterior, posterolateral, and posteromedial reach distances on the SEBT, medial/lateral and anterior/posterior ground reaction force TTS, directional postural stability indices, and a composite dynamic postural stability index (DPSI), were assessed using mixed model ANOVA (α=0.05) and effect sizes (d).

Results: No group X direction interaction or group differences were observed for the SEBT (p=0.51, 0.71) or TTS (p=0.83, 0.72) measures. A group X direction interaction was found for postural stability indices during the forward landing task (p<0.01). Both Hip/Thigh/Knee and Lower leg/Ankle/Foot INJ groups demonstrated a greater vertical postural stability index (VPSI) (p=0.01 for both, d=0.80, 0.95) and DPSI (p=0.01, 0.02, d=0.75, 0.93) when compared to CON suggesting impaired balance control. A group X direction interaction was also found for postural stability indices during the lateral landing task (p=0.03). Only the Hip/Thigh/Knee INJ runners displayed a greater VPSI (p=0.01, d=0.81) and DPSI (p=0.017, d=0.89) when compared to CON.

Conclusions: When compared to CON, INJ runners demonstrated impaired dynamic control of vertical forces when performing the single leg landing and stabilization tasks. Clinicians should consider addressing dynamic control of vertical loads through functional tasks during the rehabilitation of running injury.

Level of Evidence: Level 3

Keywords: Dynamic postural stability index, Star Excursion Balance Test, Time to Stabilization
INTRODUCTION
Over 15.5 million persons participated in running as a form of exercise in 2013. However, running is not without its risk of injury. Nearly 80% of runners sustain some type of injury each year. Additionally, sustaining a running injury is one of the strongest predictors of future injury in runners. Thus, it is essential to identify factors that contribute to both initial and subsequent injuries.

Lower extremity injury may negatively affect postural control and contribute to the incidence of future injuries. Postural control deficits have been observed in active populations with musculoskeletal injury, such as those with ankle injury and patellofemoral pain. However, evidence examining postural control in injured runners is scant. The high impact, dynamic nature of running combined with the task constraint of a narrow base of support poses a significant postural control challenge. It is possible that underlying postural control deficits may partly explain altered mechanics commonly observed in runners with injury.

Since running is a dynamic activity, traditional static postural control measures may not be sensitive to deficits. Three dynamic measures that have been reported to be reliable and sensitive to group differences in active populations include Time to Stabilization (TTS), the Star Excursion Balance Test (SEBT), and the Dynamic Postural Stability Index (DPSI). All three measures evaluate single leg capability. TTS is a dynamic postural control measure which quantifies the time to stabilization of the ground reaction forces (GRF) during the time period following a single leg landing. Specifically, TTS describes the time it takes for the GRF vector of interest to fall within a pre-determined GRF range, i.e. stabilize, following a jump landing. TTS is thought to reflect lower extremity strength, proprioception, and postural control at the hip, knee, and ankle joints during single leg landing and is reported to be longer in persons with ankle injury. Test-retest reliability of TTS in anterior-posterior (AP) and medial-lateral (ML) directions has been previously examined with ICC values ranging between 0.65-0.79.

The SEBT is a dynamic postural control test that requires flexibility, proprioception, and strength. It is designed to assess the ability to move safely and effectively outside one's base of support. To perform the SEBT, the participant must stand in single limb stance and maximally reach with the non-weight bearing limb in multiple directions without weight bearing on the toes of the reaching leg or losing their balance. Distance reached is the outcome measure and is considered to reflect dynamic postural control with a greater reach distance corresponding with better postural control. Distance reached has been prospectively linked to lower extremity injury. Intrarater reliability (ICC) of the SEBT has been reported to range between 0.84-0.87 with test-retest reliability ranging from 0.89-0.93 for the anterior, posteromedial and posterolateral reach directions.

The DPSI assesses the variation of the GRFs following a single leg landing. Specifically, the DPSI calculates a composite modified root mean square using each GRF component (ML, AP, and vertical) to reflect variability in forces following a jump landing task. Directional indices can also be examined. The DPSI is a reasonably simple test to perform that requires participants to land on a force platform following a hop and has been found to be greater following ankle injury when compared to controls, suggesting poorer postural control. With the exception of the ML index, this test has been reported to have excellent test-retest reliability with ICC values ranging between 0.92-0.99. The ML index (ICC = 0.38) is suspected to be less reliable due to the variable nature of the ML GRF during single leg landing.

The purpose of this study was to examine dynamic postural control in injured (INJ) and uninjured runners (CON) using TTS, SEBT and DPSI. It was hypothesized that dynamic postural control differences would exist between injured and uninjured runners.

METHODS
Subjects
University Institutional Review Board approval for this study was obtained. All subjects signed written informed consents prior to participation. Based on a-priori power analysis (G*Power Version 3.0.10), forty-four runners (22 with history of injury (INJ) and 22 controls (CON)) were recruited. For each participant recruited for the INJ group, a control participant with no history of injury matched on...
gender, age, self-reported running mileage, mass, and height was recruited. Self-reported 5k pace was recorded. Inclusion criteria were as follows: runners aged 18-45, currently running >10 miles per week, and in good overall health. To be considered in the INJ group, runners had to have experienced a moderately severe lower extremity injury, operationally defined as an injury that interrupted training (i.e. stopped running activity) for greater than seven days within the prior 24 months. Due to the retrospective nature of this study, this time loss definition of injury was selected to minimize participant recall bias and because it did not require medical expertise for injury diagnosis. At the time of data collection, injured participants were required to have returned to at least 50% of their pre-injury running volume without pain or limitation. Participants were excluded from the study if they were pregnant, or had a history of lower extremity surgery.

**Procedures**

Upon arrival to the laboratory, anthropometric data were collected including height, weight, and limb length. All subjects were issued standardized footwear (625, New Balance, Boston, MA) and completed a five-minute warm-up on the treadmill, running at a self-selected pace. Maximal vertical jump height was determined using the VerTeC® jump measurement tool (Sports Imports, Columbus, OH) for later use in normalizing jump technique. Dynamic postural control assessment conditions for time to stabilization (TTS), Star Excursion Balance Test (SEBT), and postural stability indices were then performed in a randomized order. In runners with a history of injury, measurements were recorded from the previously injured limb for comparison with the corresponding limb of the matched control subject. For runners with bilateral injuries, the limb with the most recent injury was studied. Study limbs were matched based on leg dominance such that if the dominant leg was the study limb (i.e. injured limb) for an INJ runner, the dominant limb of the matched control was tested.

The jump-landing task associated with TTS required participants to jump 50% of their maximal vertical jump height from both feet 70 cm behind the force platform as they hopped forward to land in single leg stance on a force platform sampled at 1200 Hz (Bertec Corp, Columbus, OH). Subjects were instructed to place their hands on their hips upon stabilization and balance for 10 seconds. Each subject performed three practice trials, after demonstration, and seven testing trials. A trial was discarded and repeated if the subject was not able to maintain their desired body position for the entire time or if they failed to reach the 50% height target.

The SEBT consisted of unilateral lower extremity reaches in the anterior, posterolateral, and posteromedial directions while maintaining single leg stance. Each direction differed from the two other directions by 120 degrees. All subjects were provided four practice trials, after demonstration, and were allowed to use their preferred movement strategies, but were asked to keep their stance leg heel down and hands on hips during the assessment. A rest period of one minute was given between practice and testing trials. After the rest period, each subject completed three trials in each of the designated directions. The distance for each trial was recorded by the trained researcher and normalized to subject’s leg length. For each direction, the mean reach distance of three trials was used in statistical analysis. The order of the directions was randomized using a random number generator. Trials were repeated when participants placed a substantial amount of weight on the reaching leg, placed their foot down to restore balance, moved their stance leg from the middle of the grid, or failed to return their reach leg to the starting position.

For assessment of postural stability indices, participants were asked to perform five successful single leg hops over a 12” hurdle in both the anterior and the lateral directions (Figures 3 and 4) onto a force platform sampled at 1200 Hz (Bertec Corp, Columbus, OH). The direction of the lateral hop always occurred towards the leg to be tested. Participants began in double leg stance from a distance corresponding 40% of their height from the force platform for the anterior hop and 33% for the lateral hop. They were allowed to use their arms to propel themselves and maintain their postural control, but were cued to stabilize their body as quickly as possible after landing on the force platform and place their hands on their hips upon stabilization. Prior to data collection, each subject performed as many practice trials as needed in order to become familiar with...
The testing procedure. Following a two minute rest period, subjects completed five test jumps in each direction. GRF data were collected for 10 seconds following initial contact with the force plate. Five trials have been shown to provide excellent reliability during similar single leg hop tasks for dynamic postural control indices \((\text{ICC} = 0.90-0.97)\).\(^{23,24}\) If the subject flailed their arms during the terminal stabilization period, missed the force platform, touched the hurdle, touched the ground with the opposite leg, or did not jump off both feet, the trial was repeated. Condition order was randomized and runners were given two minutes of rest between jump directions.

**Analysis**

Force data from jump landing tasks were filtered using a zero-lag fourth order low pass Butterworth filter with a 20 Hz cutoff frequency. Times required for medial/lateral (ML) and anterior/posterior (AP) ground reaction forces (GRFs) to stabilize after a jump landing were calculated from seven vertical jumps.\(^{24}\) Since injury has been reported to influence postural control, a reference point for stability was calculated using the healthy control data in the manner of Ross et al.\(^{12}\) Next, AP and ML GRF for each trial were fitted to an unbounded third-order polynomial line of best fit. The time point at which the value of the third-order polynomial line fell below the pre-determined stable state AP or ML value was recorded as the TTS for that trial. For both AP and ML GRF, the mean TTS of seven trials were exported for statistical analysis.

Directional postural stability indices (ML, AP, and vertical) and the composite dynamic postural sta-
The DPSI index was calculated using the following equation:

\[ \text{DPSI} = \sqrt{\sum (0-\text{GRFx})^2 + \sum (0-\text{GRFy})^2 + \sum (\text{body weight}-\text{GRFz})^2 / \text{number of data points}}\]

Intraclass correlations (ICC) were calculated using trial data for all variables to describe the reliability (i.e. consistency) of measurements in this study population. Overall group X direction mixed model ANOVAs (\(\alpha = 0.05\)) and Cohen’s d effect sizes (d) were used to examine differences in the TTS, SEBT and DPSI measures. Post hoc analysis evaluated pairwise comparisons for group differences with a Bonferroni adjustment for multiple comparisons. Because site of injury may influence postural control, the INJ group was secondarily stratified into Hip/Thigh/Knee and Lower Leg/Ankle/Foot groups by a physical therapist for follow up analysis. Additionally, since the time from injury may have the potential

![Figure 2. Star Excursion Balance Test (SEBT) required the participant to reach in the a) anterior, b) posterior lateral, and c) posterior medial directions while maintaining a stationary single limb stance on the tested limb with their hands upon their hips.](image-url)
to influence postural control, bivariate correlations between time elapsed from the time of injury and postural control variables were examined.

RESULTS

Group demographics are reported in Table 1. Average time from injury for the injured group was 9.2 (SD 3.5, range 3-16) months with all but one participant reporting an injury in the year prior to time of data collection. Ten runners were stratified into a Hip/Thigh/Knee injury group and 12 were stratified into a Lower Leg/Ankle/Foot group. Table 2 presents means and standard deviations for all variables of interest.

Reliability indices (ICC) for TTS of medial-lateral and anterior-posterior GRF stabilization were 0.97 and 0.99, respectively. No group (INJ vs CON) X direction interaction or group differences were observed for TTS (p = 0.831, 0.720). When stratified by injury site, no additional differences were observed (p > 0.05). The correlations between time from injury and ML and AP TTS were -0.042 (p = 0.875) and 0.123 (p = 0.616), respectively.

SEBT reliability indices (ICC) were 0.99 for anterior reach, 0.98 for posterolateral reach, and 0.99 for posteromedial reach. No group X direction interaction or group differences were observed for the SEBT (p = 0.510, 0.710). When stratified by injury site, no additional differences were observed (p > 0.05). The correlations between time from injury and posterolateral, posteromedial, and anterior reach were 0.144 (p = 0.555), 0.206 (p = 0.398) and 0.192 (p = 0.432), respectively.

Figure 3. The forward hop of the Dynamic Postural Stability Index (DPSI) required the participant to perform a forward hop over a 12 inch hurdle landing on their tested limb. To complete the forward hop task, a) subjects began the jump from a distance of 40% of their height behind the most posterior edge of the force platform while b) hopping anteriorly over a 12 inch hurdle to landing on a single leg upon the force platform. c) Subject following stabilization after the forward hop.
The reliability (ICC) of postural stability indices in the forward landing task were 0.68 for ML PSI, 0.97 for AP PSI, 0.99 for V PSI and 0.99 for composite DPSI. A significant overall group by direction interaction was found for the postural stability indices during the forward landing task (p = 0.009). Specifically, the injured runners demonstrated a greater V PSI (p = 0.013, d = 0.875) and composite DPSI (p = 0.016, d = 0.836) compared to non-injured runners. Stratified analysis revealed that both the Hip/Thigh/Knee INJ runners (p = 0.011, d = 0.95) and the Lower Leg/Ankle/Foot INJ runners (p = 0.014, d = 0.80) demonstrated a greater V PSI compared to non-injured runners during the forward landing.

Table 1. Subject demographics and self-reported running volume and pace

<table>
<thead>
<tr>
<th></th>
<th>Height (cm)</th>
<th>Mass (kg)</th>
<th>Age (yrs)</th>
<th>Weekly Run Distance (mi)</th>
<th>5k pace (m/s)</th>
<th>Gender</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>Mean</td>
<td>172.87</td>
<td>66.81</td>
<td>22.33</td>
<td>25.68</td>
<td>3.71</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>11.20</td>
<td>13.32</td>
<td>1.95</td>
<td>17.82</td>
<td>0.69</td>
</tr>
<tr>
<td>Injured</td>
<td>Mean</td>
<td>172.56</td>
<td>67.93</td>
<td>22.00</td>
<td>29.43</td>
<td>4.00</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>9.94</td>
<td>12.00</td>
<td>3.22</td>
<td>21.01</td>
<td>0.64</td>
</tr>
<tr>
<td>p-value</td>
<td></td>
<td>0.92</td>
<td>0.77</td>
<td>0.69</td>
<td>0.53</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Figure 4. The lateral hop of the Dynamic Postural Stability Index (DPSI) required the participants to perform a lateral hop over a 6 inch hurdle landing on their tested limb. To complete the lateral hop, a) subjects began the jump from a distance of 33% of their height from the most lateral edge of the force platform and b) hopped laterally over a 6 inch hurdle upon the force platform. c) Subject following stabilization after the lateral hop task.
Table 2. Means and standard deviation of variables of interest for all groups. The INJ group was stratified by site of injury for secondary analysis. Statistically significant pairwise comparisons (p < 0.05), when compared to controls, are indicated by asterisks (*).

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>All INJ</th>
<th>Lower Leg/Ankle/Foot INJ</th>
<th>Hip/Thigh/Knee INJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to Stabilization (s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ML GRF</td>
<td>2.58 (0.81)</td>
<td>2.51 (0.94)</td>
<td>2.39 (0.72)</td>
<td>2.65 (1.18)</td>
</tr>
<tr>
<td>AP GRF</td>
<td>2.44 (0.15)</td>
<td>2.41 (0.15)</td>
<td>2.40 (0.10)</td>
<td>2.44 (0.20)</td>
</tr>
<tr>
<td>Reach Distance (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior</td>
<td>0.79 (0.12)</td>
<td>0.79 (0.14)</td>
<td>0.82 (0.16)</td>
<td>0.75 (0.11)</td>
</tr>
<tr>
<td>Postero medial</td>
<td>0.86 (0.16)</td>
<td>0.85 (0.20)</td>
<td>0.88 (0.26)</td>
<td>0.81 (0.17)</td>
</tr>
<tr>
<td>Postero lateral</td>
<td>0.87 (0.11)</td>
<td>0.83 (0.11)</td>
<td>0.85 (0.12)</td>
<td>0.82 (0.11)</td>
</tr>
<tr>
<td>Forward Hop PSI (N)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AP</td>
<td>87.28 (11.54)</td>
<td>90.18 (13.62)</td>
<td>86.08 (12.79)</td>
<td>95.09 (13.53)</td>
</tr>
<tr>
<td>ML</td>
<td>13.55 (3.61)</td>
<td>12.65 (3.54)</td>
<td>11.72 (3.18)</td>
<td>13.77 (2.78)</td>
</tr>
<tr>
<td>Vertical</td>
<td>211.26 (25.88)</td>
<td>225.81 (75.94)*</td>
<td>225.65 (84.94)*</td>
<td>226.00 (68.09)*</td>
</tr>
<tr>
<td>Composite DPSI</td>
<td>202.14 (26.79)</td>
<td>244.46 (74.48)*</td>
<td>242.99 (82.68)*</td>
<td>246.22 (67.70)*</td>
</tr>
<tr>
<td>Lateral Hop PSI (N)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AP</td>
<td>42.18 (34.49)</td>
<td>43.65 (29.26)</td>
<td>46.36 (36.40)</td>
<td>42.39 (39.87)</td>
</tr>
<tr>
<td>ML</td>
<td>43.22 (31.01)</td>
<td>44.55 (37.14)</td>
<td>37.53 (26.78)</td>
<td>50.99 (31.81)</td>
</tr>
<tr>
<td>Vertical</td>
<td>171.28 (31.94)</td>
<td>186.70 (56.61)</td>
<td>161.29 (36.30)</td>
<td>217.19 (38.82)*</td>
</tr>
<tr>
<td>Composite DPSI</td>
<td>186.88 (34.27)</td>
<td>194.57 (47.03)</td>
<td>177.11 (28.65)</td>
<td>232.43 (68.40)*</td>
</tr>
</tbody>
</table>

Similarly, both the Hip/Thigh/Knee (p = 0.012, d = 0.93) and the Lower Leg/Ankle/Foot INJ runners (p = 0.019, d = 0.75) demonstrated a greater composite DPSI compared to non-injured runners during the forward landing. No differences were observed in the AP or ML PSI (p > 0.05). The correlations between time from injury and ML PSI, AP PSI, V PSI, and composite DPSI for the forward landing task were -0.009 (p = 0.971), -0.041 (p = 0.867), 0.020 (p = 0.936) and 0.019 (p = 0.939), respectively.

The reliability indices (ICC) of postural stability index measures for the lateral landing task were 0.99 for ML PSI, 0.99 for AP PSI, 0.97 for V PSI and 0.98 for composite DPSI. No interaction or overall group differences in the postural stability indices were found for the lateral landing task (p = 0.576 and 0.293, respectively). However, a group X direction interaction was found for postural stability indices during the lateral landing task when groups were stratified by injury site (p = 0.030). The Hip/Thigh/Knee INJ runners displayed a greater V PSI (p = 0.007, d = 0.91) and composite DPSI (p = 0.010, d = 0.89) compared to non-injured runners. No other group differences were observed nor were differences observed in the AP or ML directions (p > 0.05). Correlations between time from injury and ML PSI, AP PSI, V PSI, and composite DPSI in the lateral landing task were -0.249 (p = 0.304), 0.124 (p = 0.613), -0.512 (p = 0.025) and -0.495 (p = 0.031), respectively.

DISCUSSION
Running is a dynamic task requiring the control of the center of mass over an ever changing, narrow base of support. The aim of this study was to identify if dynamic postural control deficits reflected in TTS, SEBT, and DPSI measures were present in runners with a history of injury. Contrary to the proposed hypothesis, TTS and SEBT assessments did not detect any meaningful differences in stabilization times or reach distances, respectively, between injured and control groups. However, postural stability indices did detect group differences in postural control as hypothesized. Specifically, injured runners demonstrated greater GRF variability following a forward hop in both the V PSI and composite DPSI measures. The Hip/Thigh/Knee INJ group also displayed greater GRF variability following a lateral hop in both
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is suggestive of decreased postural control during dynamic landing tasks in runners with injury. Interestingly when compared to controls, both groups of INJ runners demonstrated altered postural control during the forward hop task, the task that most closely mimicked running. However, only the Hip/Thigh/Knee INJ displayed altered postural control in the lateral landing task. Given the nature of this task, it is possible that greater proximal control was demanded and thereby presented a greater relative task difficulty for the Hip/Thigh/Knee INJ group, a group commonly cited as having impaired proximal control. Overall, these results appear to suggest that postural stability indices during landing tasks may be useful in identifying postural control deficits in runners with injury and should be considered in future analyses. Additionally, while retrospective injury appears to influence postural control during dynamic landing tasks, future prospective studies are needed to establish causation.

The results of DPSI findings in this study are consistent with previous work in other populations. Wikstrom et al studied individuals with self-reported ankle instability vs. healthy controls and also found that subjects with ankle instability demonstrated higher postural stability index values in both the V PSI and composite DPSI during a forward landing task; however, the lateral landing stabilization task was not investigated. Investigators proposed that the observed postural deficits may be due to residual insufficiencies from the initial injury. An athlete may no longer have the appropriate dynamic postural responses after injury to optimally respond to perturbations, especially to those as large as the vertical GRF forces during single leg landing. For example, injury may result in reduced proprioceptive abilities due to mechanoreceptor damage and sensory reorganization. Without proper sensorimotor function, an individual may possess a decreased ability to sense perturbations and therefore have a reduced ability to elicit reactive or protective motor responses to prevent injury. Previous work suggests that injured runners may demonstrate altered proprioception and plantar sensation thereby providing a partial explanation for the impaired postural control in response to vertical forces. Additional factors such as muscle strength, muscle activation, and sensory integration deficits have the potential
to contribute to observed deficits in dynamic postural stability and impact attenuation as well. Unfortunately, these factors were not examined in the current study and future study is needed to better understand how these may influence the dynamic postural control in injured runners.

While others have reported TTS and SEBT differences in high functioning injured populations, group differences were not observed in the current study using these measures. These results contrast with the results from previous studies examining TTS in subjects with and without a history of functional ankle instability, chronic ankle instability, and patellofemoral pain syndrome. Similarly, this study's results contrast others using the SEBT in populations with and without chronic ankle instability, ACL reconstruction, patellofemoral pain. While none of the previous studies have examined running injury specifically per se, running is likely inherent to many of the populations that have been previously investigated. Thus, it is possible that TTS after a jump task and the unilateral limb reach distance over a stable base of support may not be sensitive to postural stability deficits in runners after injury. However, it is also important to note that injured runners likely develop compensation strategies to minimize pain in order to maintain a running program. For example, a runner may decrease their available degrees of freedom in lower limb joints by increased co-contraction, and in effect become “stiffer” upon impact. This compensation strategy may serve to mask the postural deficits such that increased measures of postural stability would not be observed. This effect has been observed in dynamic measures of postural sway in individuals with chronic ankle sprains. Group analysis in this study does not suggest that this strategy was employed by the majority of subjects studied. However, future analyses should consider individual response patterns.

The injury definition used in this study was quite broad where runners with a history of either repetitive or acute injuries during the previous two years were included in an attempt to generalize any potential findings. This definition was chosen since previous prospective work has suggested that a history of any injury to the lower extremity is the single biggest predictor of running injury. Moreover, postural control could be compromised by a variety of injuries, but has not been examined in runners. Thus in this first step, a broader definition of injury was warranted. A review of the study population revealed that a large majority (18 out of 22) of injured runners reported a history of overuse injuries (i.e. patellofemoral pain syndrome, plantar fasciitis, tendonitis, stress fracture). The removal of the four participants who had sustained acute injuries and their matched controls did not change the overall findings in the current study. In addition, the time from injury was not related to the majority of the postural control measures examined in this study other than the VPSI and composite DPSI during the lateral landing task. While it is unclear as to the specific reason, the lateral landing task was the most challenging for participants which may help explain why postural stability indices decreased as time from injury increased. While some consider a time loss definition of injury rather narrow, this definition was chosen to minimize participant recall bias as it is likely easier to recall injuries of greater severity. Gabbe et al has shown that participants can accurately recall injuries that occurred within the previous year. Examination of the subject pool in the current study revealed that only one participant reported a time from injury exceeding 12 months. Exclusion of that data as well as their control did not change the results of this study. Other factors such as injury severity, number of injuries and rehabilitation experience may have also differentially influenced postural control findings. Despite susceptibility to biases, case control studies examining the effects of retrospective injury examination associations and provide a foundation for intervention and prospective injury investigations. The results of this study appear to indicate that efforts should be made to improve dynamic postural control following injury in runners and the use of dynamic postural control assessments warrants further investigation in this population. Identification of clinically feasible tests that can be done outside the laboratory and analyses that are sensitive to group differences are needed. Additionally, prospective studies are warranted.

**CONCLUSION**

In conclusion, the results of this study indicate that dynamic postural control, particularly related to the
attenuation of vertical forces, may be impaired in runners with a history of prior injury as compared with healthy runners. Increased vertical GRF variability in landing, which may be related to decreased dynamic postural stability, was observed in injured runners following a forward hop and single-leg stabilization task. Additionally, runners with Hip/Thigh/Leg injury, but not Lower Leg/Ankle/Foot injury, were similarly challenged with a lateral hop and single-leg stabilization task. Based on these results, it appears that dynamic postural stability indices during landing tasks may be relevant parameters to detect postural stability impairment following running injury. Clinicians should consider addressing dynamic control of vertical loads through functional tasks, such as single-leg landings, during the rehabilitation after running injury. Additional research appears warranted to identify clinically relevant measures of dynamic postural control that are both sensitive to group differences and feasible to measure prospectively in the clinical environment.

REFERENCES


21. Wikstrom EA, Tillman MD, Chmielewski TL, Cauraugh JH, Naugle KE, Borsa PA. Discriminating...


ABSTRACT

Background: Generalized joint laxity is more prevalent in women than men and may lead to poorer post-operative outcomes in select orthopedic populations. There are no studies examining peri-operative function in patients with generalized joint laxity (GJL) and femoroacetabular impingement (FAI).

Purpose: The purpose of this study was to determine the difference in perceived function and quality of life as measured by the Hip Outcome Score ADL subscale (HOS-ADL), International Hip Outcomes Tool (iHOT-33) and the Short Form 12-Item Health Survey (SF-12) in women with and without GJL prior to and six months after undergoing hip arthroscopy for FAI.

Study Design: Cohort Study

Methods: Peri-operative data were collected from women with FAI from November 2011-September 2014. Lax subjects were women with laxity scores ≥4/9 on the Beighton and Horan Joint Mobility Index; Nonlax subjects were women with laxity scores <4/9. Functional outcomes were evaluated using the HOS-ADL, iHOT-33, PCS-12, and the MCS-12 pre-operatively and at 6 months post-operatively. Change scores (post-score – pre-score) were calculated for each outcome measure and compared between groups, along with pre-operative and post-operative means, using Mann-Whitney U tests.

Results: 166 women met the inclusion criteria: Nonlax (n=131), Lax (n=35). There were no statistically significant differences between groups in pre-operative functional outcomes (all p > .05). Additionally, there were no statistically significant differences between groups in post-operative means or change scores, respectively, for HOS-ADL (p = .696, .358), iHOT-33 (p = .550, .705), PCS-12 (p = .713, .191), and MCS-12 (p = .751, .082). Laxity score was not associated with any post-operative functional outcome score or change score (all p > .05).

Conclusion: Women with and without generalized joint laxity do not appear to report differences in hip function in the 6-month peri-operative period before and after hip arthroscopy for FAI.

Level of Evidence: 3

Key Words: Hip arthroscopy, femoroacetabular impingement, generalized joint laxity

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INTRODUCTION

Femoroacetabular impingement (FAI) is defined as aberrant contact between the proximal femur and acetabulum due to abnormal morphology of the hip joint.\(^1\) Left untreated, FAI may result in pain and disability,\(^1\) chondrolabral dysfunction,\(^2\) and future development of degenerative arthritis.\(^3,5\) Hip arthroscopy has emerged as an effective surgical management technique for FAI and associated labral pathology,\(^4\) yielding high patient satisfaction and significant improvements in patient self-reported outcome scores for the majority of patients.\(^6,8\) However, women report lower pre- and post-operative quality of life scores\(^9\) and worse functional outcomes\(^10\) compared to age-matched men. Further, female patients were the only individuals to undergo revision surgeries for continued pain and hip dysfunction in a study of outcomes post-hip arthroscopy in adolescents.\(^10\) Understanding factors related to poorer outcomes in women undergoing hip arthroscopy may help guide the most effective peri-operative clinical decisions.

Generalized joint laxity (GJL) may be one factor that explains the difference in outcomes between sexes following hip arthroscopy. The prevalence of GJL in the general population ranges from 5-20%,\(^11\) with rates as high as 33% reported in pubertal and post-pubertal highly active females.\(^12\) Importantly, the presence of GJL may predispose individuals to injury and poorer orthopedic surgical outcomes. GJL increases the risk of knee joint injury\(^18\) and specifically increases the risk of anterior cruciate ligament (ACL) injury five-fold in young female athletes.\(^19\) GJL is also related to poorer self-reported orthopedic surgical outcomes, increased joint and musculoskeletal pain, and decreased quality of life.\(^20-22\)

Comprehensive pre-operative assessment provides critical information concerning patient care and surgical decision-making. The pre-surgical condition of the patient and the injured joint are known predictors of function following hip arthroscopy.\(^8\) In a cohort study of 112 adults scheduled to undergo hip arthroscopy for FAI with associated chondrolabral dysfunction, poorer self-reported function prior to surgery was associated with poorer post-operative outcomes; those individuals with lower Modified Harris Hip Scores were also more likely to undergo total hip arthroplasty following failure of hip arthroscopy.\(^8\) GJL may adversely affect peri-operative function in patients undergoing hip arthroscopy and could have important implications on peri-operative care and rehabilitation strategies.

While GJL complicates the clinical outcomes in some orthopaedic populations, the influence of GJL on peri-operative function in women with symptomatic FAI has not been previously investigated. The purpose of this study was to determine the difference in perceived function and quality of life as measured by the Hip Outcome Score ADL subscale (HOS-ADL), International Hip Outcomes Tool (iHOT-33) and the Short Form 12-Item Health Survey (SF-12) in women with and without GJL prior to and six months after undergoing hip arthroscopy. The primary hypothesis tested was that women with GJL would report significantly worse outcomes of perceived function and quality of life when compared with women without GJL pre-operatively and six months after hip arthroscopy. The second hypothesis tested was that BHJMI score would be associated with post-operative function in women six months after hip arthroscopy.

METHODS

This study was approved by the Institutional Review Board and The Ohio State University, and all subjects provided informed consent prior to participation. Self-reported outcomes data were prospectively collected on 664 consecutive patients undergoing hip arthroscopy for symptomatic FAI with and without associated labral pathology from November 2011 to May 2015. Study data were collected and managed using REDCap (Research Electronic Data Capture) electronic data capture tools hosted by The Ohio State University.\(^23\) REDCap is a secure, web-based application designed to support data capture for research studies, providing 1) an intuitive interface for validated data entry; 2) audit trails for tracking data manipulation and export procedures; 3) automated export procedures for seamless data downloads to common statistical packages; and 4) procedures for importing data from external sources.\(^23\) The current study was a retrospective, secondary analysis from this prospective cohort of subjects undergoing hip arthroscopy. Women who consented to undergo hip arthroscopy and had completed self-reported out-
comes questionnaires before and six months after surgery were included in this study, regardless of arthroscopic labral management (debridement, repair, or reconstruction). Subjects who were male, underwent revisions, underwent bilateral surgeries or had a history of orthopedic surgery over the six months prior to the collection of baseline data were excluded. Symptom duration was grouped into one of three categories: 0-1 year, 1-3 years and 3+ years.

Clinical Examination

Pre-operative diagnosis of FAI was confirmed by clinical examination and imaging. All subjects underwent a pre-operative medical evaluation with the treating orthopaedic surgeon (TJE). This included the collection of demographic information, medical and surgical history, and history of current condition and symptoms; the completion of self-reported outcome questionnaires; and the completion of a physical examination including pre-operative assessment of GJL.

The diagnosis of FAI was confirmed by a combination of injury history and objective examination findings, including specific intra-articular provocation tests, hip range of motion testing and results of imaging studies. Clinical guidelines for arthroscopic management for FAI included: hip pain (primarily in the groin) that interfered with activities of daily living; radiologic evidence of FAI; cam impingement (alpha angle > 50 degrees), pincer impingement (acetabular retroversion or coxa profunda) or both; failure of conservative therapy for a duration of six months including activity modification and treatment with non-steroidal anti-inflammatory drugs; and minimal degenerative changes of the hip (Tönnis grade < 1). If necessary, intra-articular source of symptoms was confirmed by relief after injection of local anesthetic into the joint. Physical examination was performed on all subjects by the same orthopedic surgeon pre-operatively. Hip provocation testing included the flexion abduction external rotation (FABER) test and the Flexion/Internal rotation test and the hip impingement test (FADIR). Radiographs, magnetic resonance imaging (MRI) and three-dimensional (3-D) computed tomography (CT) were used in the clinical assessment and for pre-operative planning. MRI was used to confirm labral tears, evaluate joint abnormalities and assess articular damage within the joint. Subjects with significant dysplasia (Lateral Center Edge Angle (LCEA)<25° and Angle of Inclination (AI)>10°) were excluded. The degree of hip osteoarthritis present on hip radiographs was determined by using the Tönnis grade classification system.

GJL was assessed using the Beighton and Horan joint mobility index (BHJMI). The BHJMI is frequently used to evaluate the presence and degree of generalized joint laxity (Table 1). A cutoff score of ≥ 4 out of 9 was used based on the revised 1998 Beighton scale (Beighton criteria) and previous studies. The BHJMI demonstrates excellent inter- and intra-rater reliability in screening for GJL in women aged 15-45. The BHJMI has also been validated against other global joint mobility scoring systems and with passive ranges of motion of multiple joints.

<table>
<thead>
<tr>
<th>Joint Examination</th>
<th>Positive Sign</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee hyperextension (each side)</td>
<td>≥ 10 degrees</td>
<td>2 (one per side)</td>
</tr>
<tr>
<td>Elbow hyperextension (each side)</td>
<td>≥ 10 degrees</td>
<td>2 (one per side)</td>
</tr>
<tr>
<td>Passive thumb to anterior forearm (each side)</td>
<td>Thumb to forearm</td>
<td>2 (one per side)</td>
</tr>
<tr>
<td>Passive fifth finger hyperextension (each side)</td>
<td>≥ 90 degrees</td>
<td>2 (one per side)</td>
</tr>
<tr>
<td>Standing trunk flexion with knee extension</td>
<td>Ability to touch the palms to the floor</td>
<td>1</td>
</tr>
</tbody>
</table>
Arthroscopic Surgery and Post-Operative Rehabilitation
Subjects included in this study underwent arthroscopy to address the bony impingement and associated labral pathology with femoral neck osteoplasty, acetabuloplasty, labral repair, labral debridement, and/or anterior inferior iliac spine resection, as indicated. Details of the surgical procedure were recorded in the database for each subject in the study. Capsular closures were performed on all patients with 3-4 sutures on all patients beginning in April of 2013 (Table 2). All subjects underwent the same supervised physical therapy program following arthroscopy with a standard set of rehabilitation guidelines, which included pain-guided weight-bearing progression, use of a continuous passive motion (CPM) machine, and family member instruction in performing passive hip circumduction in the acute phase of rehabilitation. After approximately four weeks, rehabilitation focused on restoring full pain free hip range of motion with respect to tissue healing guidelines and the progression of a previously published phased exercise program that individuals performed without pain or musculoskeletal compensation. Compliance with rehabilitation and duration of skilled physical therapy were not recorded for this study.

Self-Reported Functional Outcome Measures
Reliable and valid functional outcome measures were completed at the pre-surgical visit and six months after surgery. Self-reported hip function was assessed using the Hip Outcome Score ADL subscale (HOS ADL) and the International Hip Outcome Tool (iHOT-33). The HOS ADL is a 17-item subscale of the HOS pertaining to basic daily activities. The iHOT-33 is a 33-item visual analog scale (VAS) outcome measure recently designed for young, active patients with hip pathology. A higher score on the HOS-ADL and the iHOT-33 indicates better function, and scores are transformed to a scale of 0-100 percent. Additionally, both the HOS ADL and iHOT-33 are valid and reliable in assessing outcomes after hip arthroscopy for labral pathology and FAI. Quality of life was assessed using the Short Form 12-item Health Survey v.2® (SF-12) physical component summary (PCS-12) and mental component summary (MCS-12). Both components of the SF-12 are reliable and valid global function measures scored based on a norm-based mean of 50 with a standard deviation of 10.

Statistical Analyses
All statistical analyses were performed using SPSS software (IBM SPSS Statistics; v. 21.0; Chicago, IL). Subjects were divided into two groups for analysis based on their BHJMI score. Female subjects with BHJMI scores ≥ 4 out of 9 were classified as ‘LAX’ and those with BHJMI scores < 4 out of 9 were classified as ‘NONLAX’. Descriptive analysis of demographic data consisted of the calculation of percentages and frequencies for categorical data and the calculation of means and ranges for continuous data. Categorical demographic data were compared between groups (between LAX and NONLAX) using Chi Square tests and using Fisher exact tests when counts per group were less than five. Continuous demographic data were compared between groups using independent t-tests. Additionally, independent t-tests were used to compare pre-surgical group differences for each functional outcome score prior to surgery for all subjects with pre-surgical data. Equal variances and normality were confirmed for all pre-operative variables compared. Change scores (six-month post-operative score – pre-operative score) were calculated for each functional outcome score. However, due to non-normality of the six-month post-operative data and change scores across both the LAX and NONLAX groups, six-month group means and change scores were compared between groups using independent samples Mann-Whitney U tests. Statistical significance was established a priori (α = 0.05) for all comparisons. Linear regressions were used to test the second hypothesis that BHJMI scores would be associated with post-operative functional outcome scores six months after hip arthroscopy and change scores (post-score – pre-score). In each regression, capsule closure status was controlled for, as capsule closure during hip arthroscopy has been recommended for individuals undergoing hip arthroscopy and was not performed in the entire cohort. Capsule closure was dichotomized (No/Yes) prior to being entered into each model. After entering capsule closure status into each model, BHJMI score was entered to evaluate its impact on both post-operative functional out-
come scores and change scores. Multi-collinearity was evaluated between capsule closure status and BHJMI score with tolerance and variance inflation factors. Using an a priori significance level set at 0.05, an effect size of 0.50 (Cohen’s $d$), power of 0.8, and the distribution of individuals with laxity in this cohort, sample size was calculated to be 140 subjects (35 LAX, and 105 NONLAX) for Mann Whitney U group comparisons. Determination of a moderate effect size (0.50) was based on differences in musculoskeletal function between lax and non-lax individuals in other orthopedic populations.²⁰

### RESULTS

Of the 664 subjects in the authors’ hip outcomes database, 224 underwent hip arthroscopy for FAI. Of these, 166 (35 LAX, 131 NONLAX) met the inclusion criteria for this study, including the collection of six-month post-operative data. (Figure 1) The LAX group was younger than the NONLAX group ($p<.001$) (Table 2). However, other baseline pre-operative or operative characteristics were not significantly different between groups. (Table 2) Symptom duration for subjects varied from three to six months to greater than five years. Cam type

<table>
<thead>
<tr>
<th>Variable</th>
<th>Lax</th>
<th>Non-Lax</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Subjects</td>
<td>55</td>
<td>131</td>
<td>--</td>
</tr>
<tr>
<td><strong>Age</strong> [mean (range)], yr</td>
<td>25.7 (15-53)</td>
<td>33.5 (15-60)</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td><strong>Symptom Duration</strong>, no. of subjects (percentage)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-1 year</td>
<td>11 (31.4%)</td>
<td>27 (20.6%)</td>
<td>.209</td>
</tr>
<tr>
<td>1-3 years</td>
<td>11 (31.4%)</td>
<td>57 (43.5%)</td>
<td>.178</td>
</tr>
<tr>
<td>3+ years</td>
<td>13 (37.2%)</td>
<td>47 (35.9%)</td>
<td>.890</td>
</tr>
<tr>
<td><strong>FAI Classification</strong>, no. of subjects (percentage)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cam Lesion</td>
<td>23 (65.7%)</td>
<td>80 (61.1%)</td>
<td>.656</td>
</tr>
<tr>
<td>Pincer Lesion</td>
<td>2 (5.7%)</td>
<td>5 (3.8%)</td>
<td>.609</td>
</tr>
<tr>
<td>Combined</td>
<td>8 (22.9%)</td>
<td>40 (30.5%)</td>
<td>.347</td>
</tr>
<tr>
<td>Not Defined</td>
<td>2 (5.7%)</td>
<td>6 (4.6%)</td>
<td>.793</td>
</tr>
<tr>
<td><strong>Labral Management</strong>, no. of subjects (percentage)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labral Repair</td>
<td>31 (88.6%)</td>
<td>104 (79.4%)</td>
<td>.154</td>
</tr>
<tr>
<td>Labral Reconstruction</td>
<td>0 (0%)</td>
<td>4 (3.1%)</td>
<td>.580 ¶</td>
</tr>
<tr>
<td>Labral Debridement</td>
<td>0 (0%)</td>
<td>4 (3.1%)</td>
<td>.580 ¶</td>
</tr>
<tr>
<td>No Labral Management</td>
<td>4 (11.4%)</td>
<td>19 (14.4%)</td>
<td>.620</td>
</tr>
<tr>
<td><strong>Impingement Management</strong>, no. of subjects (percentage)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Osteoplasty</td>
<td>19 (54.2%)</td>
<td>80 (61.1%)</td>
<td>.472</td>
</tr>
<tr>
<td>Acetabular Rim Resection</td>
<td>1 (2.9%)</td>
<td>1 (0.8%)</td>
<td>.378 ¶</td>
</tr>
<tr>
<td>Combined</td>
<td>14 (40.0%)</td>
<td>50 (38.2%)</td>
<td>.844</td>
</tr>
<tr>
<td>None</td>
<td>1 (2.9%)</td>
<td>0 (0%)</td>
<td>.211 ¶</td>
</tr>
<tr>
<td><strong>Capsule Closure</strong>, no. of subjects (percentage)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>15 (42.9%)</td>
<td>65 (50.4%)</td>
<td>.474</td>
</tr>
<tr>
<td>No</td>
<td>20 (57.1%)</td>
<td>66 (49.6%)</td>
<td></td>
</tr>
</tbody>
</table>

yr = year; no. = number; * = Independent t-test group comparison; ¶ = Fisher exact test group comparison, due to small number of events; All additional group comparisons with Chi-Square tests

### Table 2. Pre-Operative Subject Demographic Data and Operative Data

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of FAI was the most prevalent bony lesion, followed by combined and isolated pincer lesions in both groups. Surgical treatment of the labrum included labral repair, labral debridement, labral reconstruction, and no labral management. (Table 2) In total, 18 subjects went on to have revision procedures (LAX, n = 4; NONLAX, n = 14) following initial index procedure. Revision procedures were agreed upon by the patient and surgeon and were based on the persistence of pain and functional limitations.

**Laxity Group Comparisons**

Prior to the completion of statistical analyses, one subject was removed as an outlier from the LAX group due to having pre-operative and post-operative functional outcome scores greater than two standard deviations below the group means for two of the functional measures. Pre-operatively, there were no statistically significant differences between groups in the HOS-ADL, iHOT-33, PCS-12, or the MCS-12 (Table 3; all p ≥ .05). Post-operatively, there were no statistically significant differences in post-operative group means (p ≥ .05) or change scores on the HOS-ADL, iHOT-33 and the PCS-12. (Tables 3, 4). Although the LAX group demonstrated greater improvements on the MCS-12 from the pre-operative to post-operative evaluation, the difference was not statistically significant (p = .082).

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**Figure 1. Consort Diagram.**
Regression Results
Multi-collinearity among independent variables in each regression model (capsule closure status, BHJMI score) allowed both predictors to be entered into each model (Tolerance=.983; Variance inflation factor=1.02). Neither capsule closure status nor BHJMI score were significantly associated with post-operative HOS-ADL score (p=.720, .876, respectively; R²=.001), iHOT-33 score (p=.452, .215, respectively; R²=.012), PCS-12 score (p=.604, .681, respectively; R²=.002), or MCS-12 score (p=.517, .568, respectively; R²=.005). Similarly, neither capsule closure status nor BHJMI score were significantly associated with HOS-ADL change score.

Table 3. Self-reported hip function and quality of life scores prior to and six months after hip arthroscopy (N=166; Lax = 35; Non-lax = 131)

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Pre-L</th>
<th>Pre-NL</th>
<th>P-value</th>
<th>Post-L</th>
<th>Post-NL</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOS ADL*</td>
<td>60.63 (54.19, 67.06)</td>
<td>60.22 (57.54, 62.90)</td>
<td>.895</td>
<td>81.93 (75.19, 88.67)</td>
<td>82.35 (79.49, 85.21)</td>
<td>.696</td>
</tr>
<tr>
<td>iHOT-33*</td>
<td>27.90 (22.61, 33.19)</td>
<td>31.52 (29.08, 33.96)</td>
<td>.188</td>
<td>62.04 (52.93, 71.14)</td>
<td>65.71 (61.64, 69.79)</td>
<td>.550</td>
</tr>
<tr>
<td>PCS-12*</td>
<td>40.99 (37.99, 43.99)</td>
<td>39.72 (38.37, 41.07)</td>
<td>.404</td>
<td>47.37 (43.79, 50.93)</td>
<td>48.51 (46.96, 50.04)</td>
<td>.713</td>
</tr>
<tr>
<td>MCS-12*</td>
<td>46.08 (42.53, 49.63)</td>
<td>49.17 (47.47, 50.87)</td>
<td>.104</td>
<td>52.10 (49.36, 54.84)</td>
<td>52.47 (51.02, 53.92)</td>
<td>.751</td>
</tr>
</tbody>
</table>

HOS-ADL = Hip Outcome Score ADL subscale; iHOT-33 = International Hip Outcome Tool; PCS-12 = Short Form 12-Item Health Survey Physical Component Summary; MCS-12 = Short Form 12-Item Health Survey Mental Component Summary

* = Mean (95% confidence interval); Pre-L=Pre-operative data for lax subjects; Pre-NL=Pre-operative data for non-lax subjects; Post-L=Post-operative data for lax subjects with 6 month follow-up; Post-NL = Post-operative data for non-lax subjects with 6 month follow-up; P-value = Independent t-test group comparisons; Φ=Mann Whitney U group comparisons

Table 4. Change scores for self-reported hip function and quality of life from pre- to 6 months after surgery (N=166; Lax = 35; Non-lax = 131)

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Lax</th>
<th>Non-Lax</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOS ADL*</td>
<td>21.29 (15.47, 27.13)</td>
<td>22.13 (19.42, 24.84)</td>
<td>.358</td>
</tr>
<tr>
<td>i-HOT-33*</td>
<td>34.14 (25.19, 43.08)</td>
<td>34.19 (30.15, 38.24)</td>
<td>.705</td>
</tr>
<tr>
<td>PCS-12*</td>
<td>6.37 (2.88, 9.86)</td>
<td>8.79 (7.24, 10.33)</td>
<td>.191</td>
</tr>
<tr>
<td>MCS-12*</td>
<td>6.03 (3.12, 8.93)</td>
<td>3.30 (1.56, 5.04)</td>
<td>.082</td>
</tr>
</tbody>
</table>

*=Mean (95% confidence interval); Φ=Mann Whitney U group comparisons; HOS-ADL = Hip Outcome Score ADL subscale; iHOT-33 = International Hip Outcome Tool; PCS-12 = Short Form 12-Item Health Survey Physical Component Summary; MCS-12 = Short Form 12-Item Health Survey Mental Component Summary
(p = .248, .754, respectively; R² = .008), iHOT-33 change score (p = .391, .414, respectively; R² = .008), PCS-12 change score (p = .196, .129, respectively; R² = .021), or MCS-12 change score (p = .620, .391, respectively; R² = .005). Additionally, because age was found to differ between the LAX and NONLAX group, the same models as those described above (six-month post-operative function; change scores) were evaluated with age included as an additional covariate. When including age in each model, neither capsule closure, BHJMI score, nor age were significantly associated with six-month post-operative function or change scores (all p > 0.05).

DISCUSSION

The primary aim of this study was to determine differences in perceived function and quality of life in women with and without GJL prior to and six months following hip arthroscopy for FAI. Differences in self-reported hip function were not identified pre-operatively or six months after surgery, refuting our hypothesis that individuals with GJL would report poorer perioperative function than those without GJL. Statistically significant improvements in post-operative scores in hip function and quality of life from pre-operative to six months were achieved following surgery, regardless of group. Additionally, to examine the impact of BHJMI scores as a continuous variable on functional outcome scores, linear regressions were performed, revealing that severity of laxity was not associated with function at six months after arthroscopy or change scores in function from the pre-operative data collection to six month post-operatively.

The effects of laxity on function have yielded mixed results in a variety of clinical populations. In a matched comparison study of 36 healthy subjects, adults with GJL (≥ 4/9) reported significantly poorer general health and greater functional limitation measured by the KOOS. Additionally, women with GJL also demonstrated significantly lower normalized knee extension strength than women without GJL. In a retrospective analysis of 272 athletes undergoing ACL reconstruction, pre- and post-operative self-reported function were not different between those with and without GJL. In this study, knee joint laxity, rather than GJL using the BHJMI, might have been associated with lower clinical outcome scores. Although GJL has been identified as a factor in lower extremity injury risk and function, it does not appear to affect self-reported function in women prior to undergoing hip arthroscopy for FAI.

To the authors’ knowledge, this is the first prospective study to examine the effect of laxity on patients who undergo surgical treatment for intra-articular hip pathology. The current data indicated that self-reported hip function and quality of life in women six months after hip arthroscopy were not affected by the presence or absence of laxity. While little data exists, the lack of differences in group outcome scores may be explained by the limitations of a single post-operative follow-up and the use of a laxity score that is not specific to the hip joint. The aim of this study was to use the BHJMI to assess global tissue laxity and its effect on function. The utility of the BHJMI at predicting specific laxity at the hip is unknown. It is possible that the presence of true hip capsular and/or ligamentous laxity may differentiate individuals postoperatively, however, specific capsular and ligamentous laxity of the hip is difficult to measure clinically.

Expectedly, these data corroborate previous findings that hip arthroscopy yields significant improvements in self-reported function in patients with intra-articular pathology; improvements that occurred regardless of GJL group allocation. The similarity in post-operative outcomes between subjects with and without GJL after hip arthroscopy may be attributed, in part, to the highly congruent joint surfaces of the hip joint. Additionally, the acetabulum has a defined concave arc of nearly 180°, and almost entirely encompasses the spherical femoral head, contributing to excellent hip joint stability. These anatomic characteristics of the hip joint limit the amount of movement that is available and may compensate for any lack of stability resulting from lax soft tissue structures in those with GJL.

Limitations

There are several limitations of this study. This sample of subjects with GJL for the six-month post-operative analysis was small relative to the number of individuals without GJL. The subjects were selected from a large database of hundreds of consecutive...
patients undergoing elective hip surgery, and data collection and recruitment is ongoing. Differences in postoperative outcomes and function after hip arthroscopy have not been studied in individuals with GJL; therefore, data from other orthopaedic diagnoses with GJL justified the use of a moderate effect size for power analysis. This may have increased the likelihood of Type II error in the present study. In addition to sample size, follow up is relatively short (six months). It has been suggested that individuals with GJL may progress at slower rates than those without GJL. Thus, changes in self-reported function may manifest between groups if followed over a longer period of time.

Lastly, individuals with hip dysplasia were not included in this cohort. Hip dysplasia may make individuals more susceptible to the effects of laxity than those with FAI. Due to the rising interest amongst surgeons and rehabilitation specialists regarding the influence of laxity on patients with FAI, the focus of this study was exclusively on a cohort of individuals with FAI. Upcoming studies should further examine the role of bony stability and post-operative outcomes following hip arthroscopy.

Future work should examine the assessment of patient self-reported outcomes and laxity at various time points (i.e. six weeks, three months, and two years) in the post-operative period. Additionally, examining the influence of specific hip joint laxity instead of global joint laxity on outcomes after arthroscopy for FAI should also be considered. Lastly, patient-specific demographic information including duration of symptoms and psychosocial factors should be assessed to determine any relationship they may have to patient outcomes following hip arthroscopy.

CONCLUSIONS
GJL does not appear to affect self-reported hip function or quality of life in the peri-operative period before and after hip arthroscopy for FAI. Regardless of the presence or absence of GJL, all patients reported significant improvements in both hip function and quality of life after surgery. Identification of variables such as generalized joint laxity may aid clinicians in adjusting the course of post-operative care.

REFERENCES:


ABSTRACT

Background: A lateral ankle sprain is the most prevalent musculoskeletal injury in sports. Exercises that aim to improve balance are a standard part of the ankle rehabilitation process. In an optimal progression model for ankle rehabilitation and prevention of future ankle sprains, it is important to characterize different balance exercises based on level of difficulty and sensori-motor training stimulus.

Purpose: The purpose of this study was to investigate frontal-plane ankle kinematics and associated peroneal muscle activity during single-legged balance on stable surface (floor) and three commonly used balance devices (Airex®, BOSU® Ball and wobble board).

Design: Descriptive exploratory laboratory study.

Methods: Nineteen healthy subjects performed single-legged balance with eyes open on an Airex® mat, BOSU® Ball, wobble board, and floor (reference condition). Ankle kinematics were measured using reflective markers and 3-dimensional recordings and expressed as inversion-eversion range of motion variability, peak velocity of inversion and number of inversion-eversion direction changes. Peroneus longus EMG activity was averaged and normalized to maximal activity during maximum voluntary contraction (MVC), and in addition amplitude probability distribution function (APDF) between 90 and 10% was calculated as a measure of muscle activation variability.

Results: Balancing on BOSU® Ball and wobble board generally resulted in increased ankle kinematic and muscle activity variables, compared to the other surfaces. BOSU® Ball was the most challenging in terms of inversion-eversion variability while wobble board was associated with a higher number of inversion-eversion direction changes. No differences in average muscle activation level were found between these two surfaces, but the BOSU® Ball did show a more variable activation pattern in terms of APDF.

Conclusion: The results showed large kinematic variability among different balance training devices and these differences are also reflected in muscle activation variability. The two most challenging devices were BOSU® Ball and Wobble board compared to Airex® and floor. This study can serve as guidance for clinicians who wish to implement a gradual progression of ankle rehabilitation and prevention exercises by taking the related ankle kinematics and muscle activity into account.

Level of Evidence: Level 3

Keywords: Ankle sprain, EMG, kinematics, rehabilitation.
INTRODUCTION

A lateral ankle sprain is the most prevalent musculoskeletal injury in sports. This injury predominantly occurs in sports where athletes are frequently exposed to jumping and side-cutting activities. Ankle inversion in a plantar-flexed foot position or ankle internal rotation in an inverted position are the most common mechanisms of ankle injury, and depending on the magnitude of the inverting moment, it may cause damage to the mechanoreceptors in the lateral ligaments and capsule. Severe injuries are often associated with the presence of residual pain, giving way sensations and neuromuscular and mechanical deficits, potentially leading to chronic ankle instability (CAI). CAI is a multifactorial condition especially associated with neuromuscular components, which often are referred to as sensori-motor deficits.

An important part of sensori-motor control of the ankle is muscle activity around the ankle joint, which contributes to ankle stability. Konradsen et al advocated that the peroneal muscles play an important role in ankle injury protection, because they are the primary evertors of the foot and ankle complex, whereby they are able to resist inverting moments potentially leading to injury. Muscle function deficits that have been reported for the peroneal muscles after ankle injury include reduced muscle activation (electromyographic amplitude) during gait and jumping tasks, reduced evertor muscle strength, and increased muscle reaction times to simulated sprains. In people with CAI, these deficits are likely related to loss of sensori-motor function of the ankle, due to mechanical damage of mechanoreceptors within the ligaments and musculature and altered mechanical properties of the ligaments after the ankle trauma. Rehabilitation following an ankle sprain or recurrent sprains (CAI) is therefore recommended, and must target the restoration and enhancement of proprioceptive and neuromuscular abilities and strengthening of the muscles. Sensori-motor training seems to be an important rehabilitation modality in order to improve sensori-motor function of the ankle joint and, ultimately, reduce the risk of future sprains. Freeman was the first to propose that sensori-motor training could decrease sensori-motor deficits at the ankle by re-educating the normal mechanoreceptor pathways in the sensori-motor system. Since then numerous authors have acknowledged sensori-motor training as an effective tool for minimizing the risk of recurrent lateral ankle sprains.

When conducting sensori-motor training, the use of exercises on balance devices are a standard part of the ankle joint rehabilitation process, because they enable exercise progression. When an exercise is performed on an unstable surface, a number of authors have reported increased ankle muscle activity (EMG). In clinical practice, many different balance devices are used, such as wobble boards, soft mats, tilt boards, and BOSU® Balls. As a clinician it is important to distinguish between the different devices concerning perturbation potential and intensity. But exact knowledge on how the intensity influences ankle kinematics and muscle activity is still lacking.

In optimal ankle rehabilitation, secondary prevention also needs to be included in later stages to reduce the high risk of recurrence and minimize the risk of CAI. It is therefore important to evaluate different exercises and devices based on their level of difficulty and sensori-motor training stimulus in order to optimize rehabilitation, through specific exercises and progression models, which eventually may improve the quality of care and success of return to play, potentially reducing recurrence and CAI. A logical and simple approach to this is to analyze ankle kinematics in the frontal plane, as this plane most often is implicated in the inversion injury mechanism, during execution of balance exercises and to quantify the associated muscle activation variability. So far no studies have included both ankle kinematics and muscle activity and thereby no recommendations have been made for the progression using unstable surfaces in ankle injury rehabilitation and prevention. Both variables may be important in injury rehabilitation and prevention, to choose optimal progression from one balance exercise to another.

The purpose of this study was to investigate frontal-plane ankle kinematics and associated peroneal muscle activity during single-legged balance on stable surface (floor) and three commonly used balance devices (Airex®, BOSU® Ball and wobble board).
METHODS

Subjects

Nineteen healthy subjects, 10 male and 9 female with age, body mass, and height at 28.8 ± 2.3 (range 20-31 years), 71.9 ± 11.5 (range 55.4-93.4 kg), and 177.2 ± 11.3 (range 158.3-195.5 cm), respectively, volunteered to participate in the study and were all included by convenience sampling. All subjects were active in sports, corresponding to 5.2 ± 3.0 hours per week (range 1-13.5 hours). The study included: men or women between 20 and 35 years of age who were active in sports which required frequent jumping or side-cutting movements such as soccer, handball, basketball, and Crossfit. The exclusion criteria included: any history of a lower extremity injury or any structured rehabilitation or self-directed sensori-motor training in the preceding six months, not including strength training in general. All subjects were told not to perform strength training 48 hours prior to testing, in order to avoid delayed onset muscle soreness (DOMS) during testing. Other cardiovascular activities such as running, swimming or biking were permitted. None of the subjects reported a history of neurological or vestibular impairments. According to Danish law, the local ethics committee did not need to perform a full ethics review, because the exercises were all commonly used in standard training programs and due to the non-invasive character of the study. All subjects gave their informed consent, according to the Helsinki Declaration, before participation in the study.

Test protocol

The test session included evaluation of single-legged shod balance on four different surfaces – the floor, an Airex® mat, the convex side of a BOSU® Ball, and a multi-directional wobble board (Figure 1), with a maximal tilt angle of 21°. The wobble board, Airex® and BOSU® Ball were all included as they are commonly used for injury prevention and rehabilitation of lower extremity injuries.31–36 Furthermore, exercises on wobble board have well-documented effect on prevention of recurrent ankle sprains 21–25 and “giving way” episodes.37 Initially, anthropometric data were collected followed by a screening of limb dominance using a performed kick-test.38 The limb used for kicking a ball was defined as dominant and subsequently used for measurements during the session. All subjects were instructed verbally and permitted three short practice trials in each condition before completing three, valid, 15-second duration trials, which were recorded. The test protocol ensured that exercises were performed in randomized order with 30-second breaks between trials to avoid muscle-fatigue. Randomizing the order of exercises was done manually by writing down all exercises on different papers, which were folded and blinded to a drawer, who finally draw one exercise from another from a bowl for each of the subjects. During all trials subjects had eyes open and the contralateral knee was maintained flexed in a 70-90 degree angle. A trial was discarded if the subject could not keep the balance for the 15 seconds or required any correction such as re-adjusting their position by moving the foot or touching the floor/balance device with the opposite foot. During all the test sessions this only happened three times across all subjects.

DATA ACQUISITION

Kinematic data

An eight camera Vicon 612 Vcam motion capture system (Oxford Metrics Ltd., Oxford, UK) was used to track the three-dimensional trajectories of reflective markers placed on the foot, ankle and shank of the subjects. Two markers attached to the surface of the subjects’ shoe corresponding to the head of first and fifth metatarsal were used to calculate the frontal plane movements of the foot, and as such be used as an estimate of the variation and amplitude of inversion and eversion movements of the ankle. Recordings were synchronized to Vicon 612 Workstation and marker positions were sampled at a frequency of 100 Hz. Prior to test protocol, a static capture during quiet standing in the anatomical position was recorded to permit the calculation of offset values for the two markers. Subsequently, differences in vertical displacement between the first and fifth metatarsal were used to calculate the frontal plane movements of the foot, and as such be used as an estimate of the variation and amplitude of inversion and eversion movements of the ankle. This means that MH5-MH1 > 0 indicates an everted position, and MH5-MH1 < 0 indicates an inverted position, and therefore increasing values indicate a movement towards eversion, and vice versa (Fig. 2).
EMG data

EMG signals were recorded using rectangular (20 mm x 30 mm) bipolar surface electrodes (DE-2.1, Delsys, Boston, MA, USA). The electrodes were applied to the peroneus longus according to the guidelines of Perotto et al.39 Skin surfaces were shaved, abraded and cleaned with alcohol to improve the conductivity of the EMG signals.39,40 All EMG signals were collected in a box (Myomonitor IV, Delsys, Boston, MA, USA) attached at the back of the subject. Here, data were amplified and band-pass filtered between 15-450 Hz, sampled at 1000 Hz, and wirelessly transmitted to a computer with a fixed delay of 200 ms and thereby converted from analogue-to-digital via a 64-bit A/D converter in the Vicon 612 Workstation.

Prior to the experimental procedures, overall maximal EMG value of the peroneus longus muscle (EMGmax) found during two trials of maximum voluntary contractions (MVC), was used as a reference value for normalization of peroneus longus activity during exercises. The MVC was assessed and measured for five seconds with the subject in supine position performing a maximal ankle eversion against...
Data reduction

For all trials, the first two and a half and last two and a half seconds of the 15 second recordings were discarded to ensure no postural adjustments in the beginning were captured, and to avoid muscle-fatigue in the end.\textsuperscript{42} Previously, Harput et al.\textsuperscript{43} manual resistance according to Kendall et al.\textsuperscript{41} During each trial, subjects were instructed to contract “as forcefully as possible with a gradual increase in force,” and strong standardized verbal encouragement was provided during the contraction. Subjects were given a 30 second break between trials.

Figure 2. Shows kinematic data and muscle activity during a single subject trial on the four different surfaces. The two measurements are synchronized during the 10 sec trial. $> 0$ indicates an everted position, and $\text{MH5-MH1} < 0$ indicates an inverted position, and therefore increasing values indicate a movement towards eversion, and vice versa.
have shown good to excellent reliability using this procedure in balance tests. All data were recorded, synchronously in Vicon 612 Workstation and subsequently processed offline using a custom-written matlab script (MATLAB, version 7.2).

**Kinematic data**
For each trial, the difference in height of the two reflective markers attached over the first and fifth metatarsal head were used to express the following frontal-plane kinematic variables: inversion-eversion variability was calculated as the standard deviation of the difference in marker height. The inversion-eversion variability represents the variation of the movements and could be an overall expression of instability. Inversion peak velocity was calculated as the mean peak velocity of all inversion movements occurring during the 10-second trial. The velocity represents the intensity severity of the movements and a large velocity indicates a forceful stimulus. The inversion-eversion direction changes were calculated as the total number of changes in direction in the frontal plane. This is an expression of the frequency of stimuli, affecting the sensori-motor system.

**EMG data**
For each trial, muscle activity was calculated as the average, normalized EMG amplitude to indicate average muscle activation, and muscle activation variability was calculated as the difference between the 90 and 10 % probability level of muscle amplitude probability distribution functions (APDF). A high value for this difference reflects high muscle activation variability over time. The raw EMG-signals of both static MVC-trials and balance trials were calculated as RMS-values (root-mean square) using gliding windows of 100 ms, with 99 ms overlaps.

**Statistical procedures**
Because this study used an exploratory design, no a priori sample size estimation was performed. In this study design, the subjects served as their own controls between the different test situations. In this way, the possible variability in kinematic data due to inaccurate marker placements observed in other intervention studies would not influence the results, as the markers remained in the same placement during all test situations. Data analysis was performed using SPSS 12.0 for Windows XP. Distributions of variables are presented as mean ± one standard deviation (SD). All data were statistically examined for normality of distribution using the Kolmogorov-Smirnov test for normality. Data were normally distributed and thus parametric statistics were applied. A one-way Repeated measures ANOVA of subjects during the four different conditions was applied, sphericity assessed, and Bonferroni correction was made according to the number of comparisons that were made and a level of p < 0.05 was chosen to indicate statistical significance.

**RESULTS**

**Frontal-plane kinematics**
Ankle inversion-eversion variability was significantly different between groups (p<0.001). Specifically, balancing on BOSU® Ball was more challenging (17 mm ± 5 mm) compared to floor (1 mm ± 1, p<0.001), Airex® (9 mm ± 2, p<0.001), and Wobble board (12 mm ± 6, p< 0.001). Also, ankle inversion-eversion variability showed significant differences when balancing on Wobble board and Airex® compared to balancing on floor (p<0.001). No other differences in ankle inversion-eversion variability were observed (Table 1).

Analyzing the ankle inversion peak velocity of each exercise, showed significant different peak values when balancing on BOSU® Ball (83 mm/s ± 28) and Wobble board (67 mm/s ± 38) compared to floor (2 mm/s ± 5, p<0.001) and Airex® (39 mm/s ± 16, p<0.01). Balancing on Airex also yielded significant different inversion peak velocity compared to just balancing on floor (p<0.001). No other differences in inversion peak velocity were observed (Table 1).

The number of ankle inversion-eversion direction changes showed significant differences when balancing on Wobble board (37 ± 9) compared to floor (4 ± 3, p<0.001), Airex® (19 ± 6, p= 0.000) and BOSU® Ball (26 ± 7, p=0.000). Also, the number of ankle inversion-eversion direction changes when balancing on BOSU® Ball showed significantly differences compared to floor (p<0.001) and Airex® (0.000), and furthermore balancing on Airex® yielded significant different number of direction changes compared to balancing on floor (p<0.001) (Table 1).
Peroneal muscle activity

Peroneal muscle relative activity was significantly higher when balancing on BOSU® Ball (32% ± 12%) and Wobble board (36% ± 14) compared to floor (21% ± 8, p<0.001) and Airex® (22% ± 8, p<0.001). No other differences were observed in peroneal muscle relative activity levels (Table 2).

Peroneal muscle activation variability (APDF) was significantly greater balancing on BOSU® Ball (41% ± 16) compared to floor (31% ± 13, p<0.002), Airex® (32% ± 13, p<0.001) and Wobble board (33% ± 13, p<0.001). No other differences among the exercises were observed (Table 2).

DISCUSSION

As a clinician involved with ankle joint rehabilitation it is important to distinguish between balance exercises based on their influence on ankle kinematics and muscle activity. The present study investigates ankle inversion-eversion kinematics and associated peroneal muscle activity during single-legged balance with eyes open in four different conditions. The main finding of the study was that balance exercises performed on an unstable surface dramatically increased ankle kinematics and subsequently the muscle activity variables compared to standing on a stable surface.

Other authors have investigated the effect of various balance devices on balance and neuromuscular

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### Table 1. Ankle kinematics reported as mean and (standard deviation) during single-legged balance in four different conditions (n=19)

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Ankle IV-EV variability (mm±SD)</th>
<th>Ankle IV peak velocity (mm/s±SD)</th>
<th>Ankle IV-EV direction changes (number±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor</td>
<td>1.0 ± 1.4</td>
<td>2.3 ± 5.5</td>
<td>4.2 ± 2.5</td>
</tr>
<tr>
<td>Airex®</td>
<td>9.5 ± 2.0#</td>
<td>38 ± 16#</td>
<td>18.9 ± 6.6#</td>
</tr>
<tr>
<td>Wobble board</td>
<td>11.8 ± 6.0#</td>
<td>67 ± 29*</td>
<td>37.2 ± 9.4†</td>
</tr>
<tr>
<td>BOSU® Ball</td>
<td>16.9 ± 5.6†</td>
<td>83 ± 38‡</td>
<td>26.5 ± 7.3‡</td>
</tr>
</tbody>
</table>

IV-EV = Inversion-Eversion † Indicates significantly larger than Wobble board, Airex and floor (p<0.001), ‡ Indicates significantly larger than Airex and floor (p<0.001), * Indicates significantly larger than Airex (p<0.001) and floor (p<0.001), # Indicates significantly larger than floor (p<0.001).

---

### Table 2. Normalized muscle activity (% of EMGmax) reported as mean and (standard deviation) during single-legged balance in four different conditions (n=19)

<table>
<thead>
<tr>
<th>Exercise</th>
<th>EMG average muscle activation (%±SD)</th>
<th>EMG muscle activation variability (APDF±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor</td>
<td>20.7 ± 8.5</td>
<td>30.6 ± 13.7</td>
</tr>
<tr>
<td>Airex®</td>
<td>21.9 ± 8.3</td>
<td>31.5 ± 12.8</td>
</tr>
<tr>
<td>Wobble board</td>
<td>36.1 ± 14.8‡</td>
<td>33.2 ± 13.8</td>
</tr>
<tr>
<td>BOSU® Ball</td>
<td>32.4 ± 12.6‡</td>
<td>41.3 ± 16.9†</td>
</tr>
</tbody>
</table>

ADPF: Amplitude Probability Distribution Function, † Indicates significantly larger than Wobble board, Airex and floor (p<0.009), ‡ Indicates significantly larger than Airex and floor (p<0.001).
used in the present study. The multi-directional wobble board seems to challenge the peroneal muscles more and therefore may explain the equal activity levels found in the present study.

Despite no differences in mean peroneal activity between balancing on wobble board or BOSU® Ball, the latter did show larger and more rapid inversion-eversion direction changes. This may demand more rapid and increased muscular activation, which was expressed in a more variable activation pattern of the peroneal muscles (greater APDF values) when balancing on the BOSU® Ball. These functional differences between two commonly used balance devices have not been reported previously.

The presence of CAI is still high and ankle sprains continue to pose a significant burden for the athletes as well as the society as a whole. The results of the present study could provide valuable information to the clinician in terms of optimizing the progression of rehabilitation programs towards return to play for the athlete. Potential future studies may investigate if the increased kinematic perturbations and greater variation of peroneal muscle activity when balancing on the BOSU® Ball compared to just training on the wobble board result in greater benefit from training on this device. This has not yet been investigated.

According to existing literature, it is evident, that rehabilitation should must include balance exercises on a wobble board to some extent.21–25,47 The current results may offer an explanation of these positive results by demonstrating high average peroneal muscle activity when exercising on the wobble board, although the exact neuromuscular link between increased ankle joint muscular activity, when using this surface, and muscular recruitment during e.g. sports activity is not yet known. However, has been suggested that sensori-motor training induces positive adaptations in the sensori-systems assisting postural control, including the vestibular, the visual, and the somato-sensori system, as well as the motor-system controlling motor output.30 The underlying neural adaptations have been shown to occur at different sites within the central nervous system. Sensori-motor training which increases the postural demands, seems to increase subcortical structures, while it reduces spinal reflex excitability and cortical involvement.30

control. Stanek et al 32 measured centre-of-pressure (COP) and average sway velocity during balance exercises on four different balance devices. Within the four tested devices, the BOSU® Ball seemed to be the most challenging one in terms of both COP and average sway velocity, although they, unlike the present study, investigated the BOSU® Ball with subjects standing on the convex side of the device. However, the latter study had some limitations, as the actual impact of the devices on ankle stability or neuromuscular response was not investigated, and furthermore a wobble board was not investigated although this is a device known to have an impact on ankle injury recurrence and CAI.21–24 When comparing the different training devices in this study, the BOSU® Ball induced almost twice the amount of inversion-eversion variability and amplitude of perturbation compared to the least unstable training device i.e. the Airex®. The BOSU® Ball also significantly surpassed the wobble board in severity of perturbation amplitude, but in terms of inversion-eversion directional changes, the wobble board was superior to all the other devices. It is likely that the differences occurred due to the different configuration of the BOSU® Ball and wobble board which results in a smaller base of support than the more densely constructed Airex® and flat floor. For that reason, the current results support that sensori-motor training can be progressed in difficulty by systematically reducing the base of support.56

With regard to muscle activity, the results of the current study also show greater average muscle activation level on the surfaces with the highest angular excursion during the balance exercise i.e. the BOSU® Ball and the wobble board, and lower activation levels on surface with less stability demands. These results thereby support similar findings of increased peroneal muscle activity when an exercise is performed on an unstable surface.28,29,45 However, the current results did not demonstrate any differences in mean peroneal muscle activity between the BOSU® Ball and wobble board, thereby supporting the findings of Harput et al. 43 This is in contrast to the study by De Ridder et al 45 who showed higher peroneal activity when balancing on a BOSU® Ball compared to a wobble board. One explanation for these differences could be that the latter study used a single-axis compared to the multi-directional wobble board.
The different examined balance devices may thus be ranked based on their mechanical stability demands and the resulting levels of muscle activation (Figure 3). This may be of assistance when clinicians are planning appropriate rehabilitation programs for persons with ankle joint injury. When the patient has established the ability to progress from bilateral stance to painfree single-legged balance, the results of this study indicate that rehabilitation should start with single-legged balancing on the floor and then progress to the Airex, which did not show higher levels of muscular activity but higher inversion-eversion kinematic changes in all three measurements. When the patient has established good balance on floor and subsequently the Airex®, the clinician can determine if the patient is ready to progress. The next steps would be to the wobble board and finally to the BOSU®, as the present results indicated that the BOSU® Ball is more challenging than the wobble board due to the fewer but larger and more rapid direction changes in ankle inversion-eversion kinematics, resulting in a more variable activation pattern of the peroneal muscle.

So it may be argued, that the frequent inversion-eversion directional changes and associated peroneal muscular activity monitored by proprioceptors and the protective musculature will induce an increased activation of the afferent pathways and assist in generation of a coordinated motor response and thereby establish improved stability that could be utilized in situations potentially leading to re-injury. This is corroborated by a study by Clark and Burden 48, who investigated the biomechanical effects of balance training and found faster reaction times during a perturbation as a result of a neuromuscular training programme performed utilizing a wobble board.48

When designing a rehabilitation program, it is necessary to challenge the sensori-motor system, normally starting with static balance exercise phase progressing to more dynamic balance exercises and then to a more functional phase facilitating more muscle pre-activity through sports specific movements.16 The results of this study provide a guide for increasing the level of perturbation stimulus with an associated change in peroneal muscle activity during rehabilitation of ankle injuries.

Figure 3. Shows a summary box for both ankle kinematic data and muscle activity. The surfaces go from low to high in order to the results of the study.
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The application of the results from the current study has limitations, as the study did not include all available balance devices. It is possible that other devices would have been more challenging in terms of kinematics and muscle activity. Furthermore, the study was conducted using healthy subjects. However, de Ridder et al. did not find any differences in muscle activity (EMG) between healthy subjects and subjects with CAI, and it may be speculated that healthy subjects would have less biological variation and the results from each device therefore better express the degree of perturbation as a result of the mechanical properties of the device rather than individual differences in subject balance abilities due to pathology and it may also be argued that the basic physiological characterization of the exercises performed in the present study is best performed initially in healthy subjects where biological variation is less than in subjects with pathology.

The protocol may vary from some rehabilitation situations, as the subjects in the current study performed the exercises wearing shoes. This may add a degree of additional stability compared to bare-footed situation, but on the other hand better reflect the injury situation in actual sport. In the present study, the authors focused on the peroneus longus muscle as the most important muscle to prevent inversion trauma, and we used markers on the 1st and 5th metatarsal heads to estimate the amount of inversion-eversion. We recognize that degree of plantarflexion may influence the magnitude of estimated inversion-eversion, and that other muscles may be important for stability, especially the tibialis anterior due to its dorsiflexion function placing the ankle joint in a more closed-packed position and thereby reducing the risk of injury. However, since no differences in plantar flexion across devices were evident this may not influence the outcome significantly.

CONCLUSION

The results of the current study show large kinematic variability among commonly utilized balance training devices and that these differences are also reflected in muscle activation variability of the peroneal muscles. The two most challenging balance devices i.e. the BOSU® Ball and the wobble board, show a kinematic perturbation almost twice that achieved when using the Airex® and 8-10 times that of achieved when standing on the floor. The results of this study can serve as guidance for clinicians who wish to implement a gradual progression of ankle rehabilitation and prevention exercises by taking the related ankle kinematics and muscle activity into account.

REFERENCES


ABSTRACT

Background: The foot progression angle (FPA) is related to the transverse plane rotation of the lower extremities and associated with many lower extremity conditions.

Purpose: The purpose of this study was to examine how two commonly used clinical measures, tibio-fibular torsion (TF) and hip rotation, can be used to predict FPA during gait in healthy adults.

Study Design: Cross-sectional study design

Methods: Passive hip internal and external rotation ranges of motion and TF torsion were measured with a 12-inch goniometer while the FPA (degree of toe-in/out) was measured with the GAITRite during midstance in sixty participants. The data was analyzed using a multiple regression model.

Results: Hip ER was not significant and was therefore excluded from the final model. The final model included passive hip IR and TF torsion ($F = 19.64; p < .001$; multiple $R^2 = .41$; adjusted $R^2 = .39$). Simple binary correlations showed that hip IR had a moderate negative correlation ($r = -.40$) with FPA (the greater the hip IR, the greater the in-toeing) while TF torsion had a positive correlation ($r = .39$) with FPA (the greater the external TF torsion, the greater the out-toeing).

Conclusions: Greater amount of passive hip IR predicts in-toeing while greater TF torsion predicts out-toeing of the foot during midstance phase of gait.

Level of Evidence: Level 2

Keywords: hip rotation, TF torsion, and foot progression angle
INTRODUCTION
Assessing the foot progression angle (FPA) during gait is an important part of a clinician's examination. The FPA is defined as the angle made by the long axis of the foot from the heel to 2nd metatarsal and the line of progression of gait. A negative FPA indicates in-toeing and a positive FPA out-toeing. Knowing the FPA may help clinicians recognize and manage a number of different lower extremity conditions including Legg-Calve-Perthes disease,¹ femoral torsion,²,³ knee OA,⁴,⁶,⁷ and plantar ulcers.⁸ In-toeing gait has also been associated with tibiofemoral (TF) torsion and sprinting speed in athletes.⁹ Thus identifying what influences the FPA and if it can be changed is important to both clinicians and coaches.

FPA is often gauged by the amount and the degree of in-toeing or out-toeing that is identified during gait assessment. FPA is also related to plantar pressure distribution; toeing-in is associated with increased lateral foot pressure while toeing-out is associated with increased medial foot pressure.⁸,¹⁰-¹² The amount of loading on the foot is important in conditions like diabetes where excessive focused pressure can result in diabetic ulcerations.⁸ Excessive out-toeing can increase medial foot pressure resulting in excessive subtalar joint pronation,¹³ and lower extremity problems such as plantar fasciitis,¹⁴,¹⁵ distal tibia fracture,¹⁶ hallux abductovalgus,¹⁷,¹⁸ and knee arthritis.⁵ Excessive lateral foot loading from in-toeing can over-supinate the foot increasing the risk of sprain to the lateral ligaments of the ankle and foot.¹⁹ Therefore, understanding the factors that can contribute or change a person's FPA during gait is important for clinicians.

A number of different authors have examined how biomechanical factors may influence the direction the foot progresses during gait.²,²⁰-²³ Two variables of the lower extremity that have been shown to contribute to the direction of FPA in adults include femoral torsion and TF torsion (also called tibial torsion).³,²⁰,²¹ Most authors have used imaging methods to determine how either femoral torsion or TF torsion relates to the rotational alignment of the lower extremity and FPA.¹²,²⁰,²⁴ Staheli²⁵ measured passive hip internal rotation (IR) and external rotation (ER) and TF torsion and the FPA in children; however he did not examine the relationship between hip rotation or TF torsion and FPA. Svenningsen²⁶ measured passive hip rotation and found a significant correlation between increased hip IR and decreased hip ER with in-toeing, but did not include TF torsion. Radler²⁴ found similar results showing a strong relationship between TF torsion and FPA using imaging methods to measure torsion, but found only a weak relationship between femoral torsion and FPA. Therapists need reliable and valid clinical measures that can help with assessing FPA. To the authors’ knowledge no studies exist that have used clinical measures of femoral and TF torsion to try to predict the direction and degree of the FPA in healthy adults.

Passive hip rotation and TF torsion are two common clinical measures used during assessment of the lower extremity in patients with musculoskeletal disorders. The purpose of this study was to examine how two commonly used clinical measures, TF and hip rotation, can be used to predict FPA during gait in healthy adults. Based on the authors’ experience, it was hypothesized that individuals with a greater amount of passive hip ER than IR and those with greater TF torsion would have a positive FPA (toe-out gait) than those with a greater amount of passive hip IR than ER and those with less TF torsion will have a negative FPA (toe-in gait).

PARTICIPANTS
Sixty participants (41 women and 19 men) with a mean age of 26.7 ± 10.9 years were recruited using convenience sampling through Maryville University. Subjects included healthy individuals between the ages of 18-65 years old (Table 1). Participants were excluded if they had previous reconstructive surgery on any joint in either lower extremity, surgery to the lower extremity in the previous six months, any neuromuscular or musculoskeletal disorder that directly affected gait, a current injury to either lower extremity.

<table>
<thead>
<tr>
<th>Table 1. Age Demographics</th>
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<tbody>
<tr>
<td>Age</td>
</tr>
<tr>
<td>18-29</td>
</tr>
<tr>
<td>30-39</td>
</tr>
<tr>
<td>40-49</td>
</tr>
<tr>
<td>50-65</td>
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</tbody>
</table>
extremity, pain with walking, inability to walk without an assistive device, or if they were unable to lie comfortably prone. The Maryville University Institutional Review Board approved this study.

**METHODS**

This was a non-experimental, cross sectional cohort study. Measured variables included passive range of motion measures of hip internal and external rotation and TF torsion. The only outcome variable was FPA (a measure of the foot toe-in or toe-out angle during midstance). All of the clinical measures were taken three times in both the left and right lower extremities and then averaged for each measured variable. Three therapists were used to collect the range of motion data, one that moved the limb, the second who aligned the goniometer, and the third that recorded the range measures. The therapist who moved the limb and the other who aligned the goniometer was blinded to the range measures taken by the third therapist. A separate therapist, without knowledge of the range of motion measures data, collected the FPA data from the GAITRite (CIR Systems, Inc., Franklin, NJ, USA). All therapists were final year DPT students who practiced the measures under the guidance of their faculty adviser.

**PROCEDURES**

Passive hip internal and external rotation was measured using a previously described method. Participants were instructed to lie prone on a treatment table while the knee was passively flexed to 90°. End range hip internal and external rotation was accomplished by grasping the distal tibia and foot and moving the hip to the end range rotation in a direction parallel to the floor where a firm end feel was appreciated. The pelvis was firmly stabilized to prevent any compensatory pelvic motion (Figure 1). A standard 12-inch plastic goniometer was used to measure hip IR and ER range of motion. TF torsion was measured using the transmalleolar (TMA) method described by Stuberg. TF torsion was assessed in the prone position with the knee flexed to 90° and the plantar surface of the foot facing upward (Figure 2). The goniometer’s stationary arm was placed along the midline of the femur and the axis of the goniometer over the calcaneus. The moving arm was placed parallel to an imaginary line that bisected both malleoli, the TMA axis. Another therapist recorded the measure of TF torsion. The validity of using the TMA method for measuring TF torsion clinically has been investigated by Lee who showed a positive moderate correlation (r = .62) when compared to CT-scans. Stuberg showed that
measuring TF torsion clinically with a goniometer with CT scans differed by an average of just 5°.

The GAITRite system (CIR Systems Inc, Franklin, NJ) was used for determining the FPA. The GAITRite has been shown to have high reliability when measuring gait speed, cadence, stride-length and toe-in/toe-out angle in young subjects (<34 years of age). The GAITRite was first calibrated according to the manufacturers directions. The GAITRite identifies a footprint during gait by sensors from a person’s heel, midfoot and forefoot that forms a trapezoid which encloses the footprint. The FPA (toe-in/toe-out angle) is the line of progression measured in degrees (defined as a line connecting two consecutive first contact points of the same foot) and the midline of the entire footprint thus displaying both face and content validity. Participants were instructed to accelerate to their comfortable walking speed within a 10-foot marked area before reaching the GAITRite walkway. They then continued this same speed the entire distance of the GAITRite walkway, and then decelerated once they stepped off the end of the GAITRite walkway. The FPA was recorded at midstance when the entire foot was in contact with the ground.

DATA ANALYSIS

Descriptive statistics including mean, standard deviation, skewness, and data normality were performed using SPSS (version 20.0). An intraclass correlation coefficient (ICC) was used to determine intra-tester reliability using the initial three measures that were gathered. Reliability data was collected using the first ten participant’s measurements to determine intra-rater reliability of goniometric measurements for hip rotation and TF torsion. A-priori a decision was made that all clinical measures must have an ICC (3,1) greater than .85. If ICC values were less than this 10 more participants were added and then re-analyze the reliability data. The intra-rater reliability for internal hip rotation ICC = .99; [CI .98-.99], for external hip rotation ranges of motion was ICC = .99; [CI .98-.99]), for TF torsion measurements was ICC = .97; [CI .97-.98], and for FPA ICC was .89; [CI .86-.92]. Data was gathered on 60 subjects; however only one side was analyzed on each subject (30 left and 30 right) to avoid “double dipping” of the data (since left and right sides are usually highly correlated). The side (left or right) that was selected was chosen by a random sampling method using the "sample" function without replacement using the statistical program R. Simple binary correlations (r) were used to determine the relationship between the different independent variables including IR and ER hip rotation and TF torsion to assess for potential collinearity. The level of significance was set at p < .05. A standard (Enter) multiple regression was utilized to see if the measured variables (passive hip IR and ER, TF torsion) could predict FPA.

RESULTS

Descriptive statistics for the participants are provided in Table 2. All of the variables used in this study showed a normal distribution for skew and kurtosis and using the Shapiro-Wilk test. Simple binary correlations performed to assess for potential collinearity among independent variables showed minor associations (hip IR and hip ER: r = -0.19; hip IR and TF torsion: r = 0.009; hip ER and TF torsion: r = 0.023) Binary correlations were also performed (after the regression modeling was complete) that compared range of motion to FPA, and hip IR had a moderate negative correlation (r = -0.40) with FPA suggesting in-toeing, while TF torsion had a medium positive correlation (r = + 0.39) with FPA suggesting out-toeing. Hip external rotation had a small but

<table>
<thead>
<tr>
<th>Table 2.</th>
<th>Descriptive statistics for the independent and dependent variables, all reported as Mean (+/- SD) in degrees.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hip IR</td>
</tr>
<tr>
<td>Male</td>
<td>33.5 (10.3)</td>
</tr>
<tr>
<td>Female</td>
<td>42.8 (9.7)</td>
</tr>
<tr>
<td>Total</td>
<td>41.2 (10.8)</td>
</tr>
</tbody>
</table>

Hip IR = hip internal rotation, Hip ER = hip external rotation, TF Torsion = tibio-fibular torsion, FPA = foot progression angle
significant correlation \((r = + 0.18)\) with FPA suggesting out-toeing. (Table 3) The positive sign or direction of the correlation suggests that the increase in hip ER is related to a toeing-out FPA. Females had greater hip IR and less ER while males had nearly symmetrical hip rotation (IR versus ER) (Table 2). A multiple regression (Enter method) entering all three dependent variables (passive hip IR and ER and TF torsion) at the same time was significant \((F = 13.42; \ p < 0.0001; \text{ multiple } R^2 = .42; \text{ adjusted } R^2 = .39)\). However, hip ER was not significant \((p > .05)\) so hip ER was dropped from the final regression model. The final regression model was significant \((F [2,57] = 19.64 \ p < .0001; \text{ multiple } R^2 = .41; \text{ adjusted } R^2 = .40)\) (Table 4).

**DISCUSSION**

The results of this study support the hypothesis that passive hip IR and TF torsion could predict or explain a meaningful amount of a person’s FPA during midstance in gait in healthy adults. Multiple regression correlation (MRC) is used to predict which variables (independent) can predict an outcome (dependent variable). Also MRC is used to determine the strength of a correlation (the Multiple R²) between the independent variables and dependent variable and also show the direction (positive or negative) of the correlations. The before-hand hypothesis was that those with greater hip IR than ER would have less FPA (in toeing or a negative correlation) and those with greater hip ER than IR and greater TF torsion would have greater FPA (out-toeing; a positive correlation). The data supported the hypothesis that those who had greater internal hip rotation were correlated with a negative FPA angle (toed-in), while an increase (external torsion) in TF torsion correlated with a positive FPA angle or a foot angle that toed-out. These results agree with a study by Stuberg et al \(28\) who noted a positive FPA (toeing-out) is often associated with increased TF torsion while a negative FPA (toeing-in) is often associated with decreased TF torsion. Although hip external rotation was not significant in the final regression model it was positively correlated \((r = .18; \ p < .05)\) with FPA (toe-out) with simple binary correlations. The mean FPA found in this study was 3.3° (with a range of -9.7° (in-toeing) to a maximum of 14.3° (out-toing), males had a mean FPA of 4.5°, while females had a mean FPA of 1.4° (Table 2). The normal FPA is an out-toeing angle of the foot that ranges from 5° in children \(11\) to 13° in adults. \(21\)

A clinical method was used to measure TF torsion using a standard goniometer, which has been shown to be valid when compared to CT scans. \(20, 28\)
The mean amount of TF torsion in the current study was +17° (an externally torsioned tibia) with a range of 4 to 31.3°. Other clinical studies found similar measures—Stuberg et al found 24° of TF torsion measured using the same method we used in a group of males and females with a mean age of 12. Adult males have a TF torsion of about +30°. When measuring the amount of TF torsion with imaging methods the quantity of TF torsion found is similar to what is found clinically. Strecker et al found a mean TF torsion of +33° using CT scan. Thus, there is quite a wide range of usual variation that exists for TF torsion; however, the tibia is normally torsioned externally.

Passive hip rotation was used as a proxy measure of femoral torsion. Anecdotally the authors believe that passive hip rotation is a more reliable clinical method of determining femoral torsion than palpating the greater trochanter, especially in those with higher BMI. Staheli suggests this method can be used clinically in children. Clinical examination of passive hip rotation has been used to estimate both the direction and the estimated amount of femoral torsion. The amount of hip IR and ER of the hip should be similar on each side (left IR = left ER), the left and right sides should be near symmetrical (left IR = right IR), and the total (left IR + left ER) hip ROM should be about 90° in healthy persons, with minor differences for age and gender. Those who demonstrate increased in-toeing often have a decrease in hip ER with an increase in hip IR, while those who toe-out have a decrease in hip IR and increase in hip ER. Interestingly, in this study females had greater hip IR and less ER while males had nearly symmetrical hip rotation (IR versus ER) (Table 2).

Previous authors who have studied femoral torsion (e.g. femoral neck anteversion) showed that passive hip rotation is correlated with femoral torsion. The degree and direction of motion asymmetry between hip IR and ER range of motion can predict the degree and the direction (ante or retroverted) of femoral torsion; however they are not accurate enough to provide the exact amount of torsion present. This suggests a relationship between the development of torsional bone deformities and the amount and direction of rotation of nearby adjacent joints in the lower extremities. Prasad suggests that torsion of the femur is brought about by muscular activity and capsular and ligamentous stress at the hip. The amount of hip internal or external rotation that children develop is often dependent on postural habits (sitting and sleeping), these extreme rotation postures may also develop in the adult. Perhaps increasing the amount of hip external rotation, through methods such as mobilization, exercise or education, in patients who display limited hip external rotation we could likely reduce the amount of in-toeing in patients (or conversely by increasing hip internal rotation can reduce out-toeing). Future studies are needed.

FPA is an important aspect of gait that clinicians should consider with lower extremity problems. Lai has shown that plantar pressure distribution of the foot during gait is determined largely by the FPA. An out-toeing FPA during gait produces greater medial plantar foot pressure while with an in-toeing FPA produces greater lateral plantar foot pressure. How the foot is loaded has important consequences in conditions like diabetes where too much focused pressure can result in ulcerations. Also loading the foot too much medially can result in abnormal mid-foot pronation. Increased medial foot loading has been related to a number of musculoskeletal problems including plantar fasciitis, which is one of the most common foot problem treated by health care providers. A FPA that allows too much foot pressure laterally can result in excessive supination of the foot increasing the risk of injury to the lateral side of the foot. FPA also dictates the direction and degree of toe-in and toe-out during gait. An increase in medial knee joint compression develops with a toe-out gait and an increase in lateral knee joint compression occurs with an in-toe gait. Thus understanding the factors that may contribute to FPA is important to clinicians when treating many different lower extremity musculoskeletal problems.

The clinical implications of this study suggests that passive hip internal rotation and TF torsion can be used to predict about 40% of a persons FPA during gait. Other potential clinical implications include the possibility of being able to modify or change these variables and to determine whether changes in them could result in changes in a persons FPA.
Understanding how to change the FPA could lead to new methods to evaluate and treat many common lower extremity musculoskeletal disorders. Strategies have already been developed to modify a person's FPA in order to reduce loading of the knee joint in patients with knee osteoarthritis. Rosebaum has shown that toe-in and toe-out gait can deliberately be changed during gait. Hunter in a single subject experimental design examined how training modified the FPA in a single patient with ITB syndrome. Recognizing a person with excessive or abnormal FPA during gait assessment can remind clinicians of the necessity to assess hip rotation for possible treatment in an effort to restore hip rotation symmetry when due to capsular or muscular restrictions.

**LIMITATIONS**

A limitation of the current study is that this study had more females than males. Females usually have a greater amount of hip IR than ER, while males usually have more ER than IR. The combined average hip IR in this study was 40°, while ER was 34° for males and females. The 19 males in this study had a lower than average amount of hip ER (mean of 34.5° hip ER) while the females had 36.7° of hip ER. A possible reason hip ER may not have been significant in the regression model was the smaller sample of males in this study that had lower amounts of hip ER than the average male. Most males in this study were symmetrical when comparing hip IR to ER, males usually have greater amounts of hip ER. Another limitation was the age of our sample. The sample was drawn mainly from college students. A previous study shows that with age hip ER is increased, especially in males. The inclusion of more males and varied ages of subjects in future studies may show the predictive ability of those with more passive hip ER for an increased toe-out FPA. Finally, metatarsus adductus of the foot was not included as one a clinical measure in this study. Metatarsus adductus is usually a problem only in infants and not likely to contribute to FPA in healthy adults. Future studies are needed to answer other potential clinical questions which include whether or not TF torsion can be modified or changed and if mutable will changes result in changes in persons FPA, understanding how to change our FPA could lead to new methods to evaluate and treat many common lower extremity musculoskeletal disorders.

**CONCLUSIONS**

The amount and direction of hip IR and TF torsion contribute to FPA. Hip IR is associated with greater in-toeing while an increase in TF torsion is associated with greater out-toeing during gait. Clinicians can use these measures to help explain a person's FPA during gait. This information can give insights as to how an abnormal FPA may be related to abnormal transverse rotations of the lower extremity when treating related lower extremity or excessive plantar pressure distribution problems. Recognizing a person with excessive or abnormal FPA during gait assessment can remind clinicians to assess hip rotation for possible treatment in an effort to restore hip rotation symmetry when due to capsular or muscular restrictions.

**REFERENCES**


ABSTRACT

Background and Purpose: Rotator cuff tendinopathy (RTCT) is regularly treated by the physical therapist. Multiple etiologies for RTCT exist, leading an individual to seek treatment from their provider of choice. Strengthening exercises (SE) have been reported to be effective in the treatment of RTCT, but there is limited evidence on the effectiveness of dry needling (DN) for this condition. The purpose of this retrospective case series was to investigate DN to various non-trigger point-based anatomical locations coupled with strengthening exercises (SE) as a treatment strategy to decrease pain and increase function in healthy patients with chronic RTC pathology.

Case Descriptions: Eight patients with RTCT were treated 1-2 times per week for up to eight weeks, and no more than sixteen total treatment sessions of SE and DN. Outcomes were tested at baseline and upon completion of therapy. A long-term outcome measure follow up averaging 8.75 months (range 3 to 20 months) was also performed. The outcome measures included the Visual Analog Scale (VAS) and the Quick Dash (QD).

Outcomes: Clinically meaningful improvements in disability and pain in the short term and upon long-term follow up were demonstrated for each patient. The mean VAS was broken down into best (VASB), current (VASC), and worst (VASW) rated pain levels and the mean was calculated for the eight patients. The mean VASB improved from 22.5 mm at the initial assessment to 2.36 mm upon completion of the intervention duration. The mean VASC improved from 28.36 mm to 5.0 mm, and the mean VASW improved from 68.88 mm to 13.25 mm. At the long-term follow up (average 8.75 months), The mean VASB, VASC, and VASW scores were 0.36 mm, 4.88 mm, and 17.88 mm respectively. The QDmean for the eight patients improved from 43.09 at baseline to 16.04 at the completion of treatment. At long-term follow-up, the QDmean was 6.59.

Conclusion: Clinically meaningful improvements in pain and disability were noted with the intervention protocol. All subjects responded positively to the intervention and reported quality of life was improved for each subject. The results of this case series show promising outcomes for the combination of SE and DN in the treatment of chronic RTCT.

Level of Evidence: Level 4

Keywords: Dry needling, rotator cuff tendinopathy, shoulder pain

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BACKGROUND AND PURPOSE
Shoulder pain is a common condition treated by Physical Therapists (PTs). It is the third most common condition treated by PTs following low back pain and neck pain.1 In the year 2000, the direct costs for the treatment of shoulder dysfunction in the United States totaled $7 billion.2 Shoulder pain occurs as a result of many different etiologies, and according to Magarey et al, the ability of a PT to accurately diagnose specific pathology in the clinic was inconsistent at best when compared to arthroscopic findings.3 Add this information to the lack of evidence supporting a specific exercise protocols and various “manual therapy” techniques to properly prescribe a rehabilitative program in the treatment of various shoulder conditions, evidence-based rehabilitation prescriptions unfortunately are scarce at best.4-9 In this age of evidence-based practice, therapists must have a foundation in best evidence to treat one of the most common conditions seen clinically.

The rotator cuff (RTC) performs multiple functions during shoulder movements, including glenohumeral abduction (ABD), external rotation (ER) and internal rotation (IR). The RTC also provides stability to the glenohumeral joint and controls translation of the humeral head. The infraspinatus and subscapularis muscles play major roles when the shoulder is abducted in the scapular plane, generating forces that are two to three times greater than supraspinatus force.10 The supraspinatus still remains more effective in ABD of the humerus due to having a more effective moment arm.10 The deltoid muscle and RTC provide significant ABD torque, and these forces are generated not only to ABD the humerus, but also to stabilize the glenohumeral joint and counter the antagonistic muscle actions or compensatory actions when pain or weakness is present.10 Relatively high force from the rotator cuff not only helps ABD the shoulder but also neutralizes the superiorly directed force generated by the deltoids at lower abduction angles.10 This all plays an important role when the RTC is kinematically out of sync due to pain and/or weakness associated with RTC tendinopathy, especially once this condition becomes chronic and compensatory activities of the shoulder complex become the preferred movement pattern employed by the body.

Dry needling (DN) research continues to be sought in the therapy community regarding its effectiveness as a treatment strategy for various conditions. Currently, there is a paucity of randomized control trials (RCT) that exists investigating the effectiveness of DN used with electrical stimulation for treatment of shoulder RTC tendinopathy. According to a recent case series, no recent systematic reviews regarding the effectiveness of dry needling for trigger points (TrPs) and myofascial pain syndromes have noted positive clinical responses to DN interventions.11 Rha et al investigated plasma-rich-platelet (PRP) injections versus DN with ultrasound guided injections into the supraspinatus tendon and found both had positive outcomes with regard to function and symptom relief (though PRP was superior at six months for symptomatic relief and functional improvement).12 To date, the majority of the studies examining the effectiveness of DN intervention have focused on TrP issues as the origin of pain.13-62 Among the DN studies published, few have looked at the effectiveness of DN outside of the TrP realm. Therefore, it seems researchers have neglected to look at the musculo-tendinous and osseo-tendinous junctions of the RTC for DN intervention, which is what clinicians are typically attempting to influence with exercise and manual therapy interventions, versus regularly focusing on treating TrP’s for shoulder pain.

Fenwick et al presented the following important information, specific to this case series, regarding the vascularity of tendons: 1) mature tendon are poorly vascularized and rely more on synovial fluid diffusion than vascular perfusion for nutrition; 2) vessels at the tendon-bone insertion anastomose with vessels of the periosteum, forming an indirect link with the osseous circulation; and 3) grafted tendons, after lengthy periods of time, are histologically identical to the original tendon.63 It has been long though that the supraspinatus, in particular has a specific de-vascularized region, which could be the reason for it’s implication in a majority of RTC pathologies, but evidence has since questioned the validity of this thought process.63 The vascular supply to tendons has been demonstrated to arise from three specific regions: the musculotendinous junction; the tendino-osseous junction; and vessels from the surrounding tissues including the paratenon, mesotenon, and the vincula.63 If this is the case, it stands to reason that DN to the musculotendinous and tendino-osseous junctions could play a
role in pain mitigation and healing of chronic RTC tendinopathies.

Both myofascial DN and TrP-DN terminology is commonly being used to denote DN intervention, yet DN is not just limited to myofascial pain or TrP intervention.\textsuperscript{11} DN is commonly used for the treatment of myofascial pain and TrPs, but may also be beneficial to treat peri-neural conditions, intramuscular conditions, symptomatic scar tissue and other various conditions that might benefit from the use of DN.\textsuperscript{11,12,64} Given the paucity of evidence for the use of DN that is not TrP directed, there is a need for the documentation and presentation of clinically relevant interventions that can assist in the treatment of chronic RCT pain. The purpose of this retrospective case series was to investigate DN to various non-TrP-based anatomical locations coupled with strengthening exercises (SE) as a treatment strategy to decrease pain and increase function in healthy patients with chronic RTC pathology.

**CASE DESCRIPTIONS**

The case series included eight patients with chronic rotator cuff tendinopathy of duration > 90 days. A retrospective review of patients for this case series included those patients who performed the exact protocol chosen for this case series, which the author does not always use for every person to avoid "cookie cutter" therapy. There were no specific inclusion/exclusion criteria, as would be used for a randomized control trial.

All eight patients were regularly engaged in exercise of some type for health and social engagement at least four times per week. Subjective questions were asked of each patient, and included thorough questioning about sleep deficit due to pain, limitations in lifting/ reaching, exercise limitations, and impaired self-care abilities due to pain, such as dressing and bathing, to provide the author with an idea of self-reported functional limitations. A review of patient histories found several common functional deficits including difficulty sleeping due to pain caused by rolling onto the affected side, limited functional use of the involved upper extremity with exercise and lifting items such as a gallon of milk due to pain and strength deficits, and other various self-care activities. The patients were all in good relative health without serious underlying pathology. A few of the patients had been previously treated by physicians and physical therapists for interventions including, but not limited to: corticosteroid injections and/or "traditional" physical therapy interventions including stretching and exercise activities, light and deep friction tissue mobilization (such as cross-friction massage/myofascial release techniques), and therapeutic ultrasound. All had taken or were currently taking over-the-counter NSAIDs for pain mitigation. Patients had not been treated for at least two months prior to the intervention for this retrospective case series. Temporary relief was reported with the previous treatment strategies, but pain had not been eliminated and there was no long-term improvement per subjective reports by each of the patients. Informed consent to participate in the series was retrospectively obtained from the patients. Human subjects research review was not required for this case series. Patients were advised that all HIPPA protected health information standards would be upheld and none of their identifying information would be released per the policies and procedures of the clinic where the treatment was performed.

**CLINICAL IMPRESSION 1**

Given the fact all eight patients had 1) previous treatment consisting of SE (either self treatment or therapist-guided), and 2) chronic shoulder pain since that time, the patients were considered appropriate for inclusion in the case series to examine the effectiveness of adding DN to a SE program. An examination of each patient was initially performed prior to intervention, in order to assess common functional limitations, strength deficits, upper extremity use limitations, and to rule out serious neurovascular pathology that might require referral to another medical specialist based upon findings. These examinations were performed before the retrospective review of subject charts for inclusion in this case series.

**EXAMINATION**

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

Posture and upper extremity active range of motion (AROM) was assessed in standing and sitting and compared bilaterally. Posture assessment included observation of cervical and thoracic curvature and head positioning at rest, scapular positioning, and scapulothoracic kinematics with AROM in abduction and flexion. Physical examination of each of the patients revealed an exaggerated flexed position of the mid to lower cervical spine and exaggerated extension of the upper cervical spine. AROM of the involved upper extremity in all eight patients showed a “painful arc” sign ranging between 70 to 125 degrees of shoulder abduction, though AROM was normal in all eight patients. No other postural abnormalities were noted.

Bilateral upper extremity (BUE) strength was assessed via manual muscle testing. Global bilateral UE MMT of each of the eight patients was normal (5/5) except for abduction and external rotation, which was found to range from 3+/5 to 4/5 for abduction, and 3+/5 to 4+/5 for external rotation in each of the patients. Pain was reported by each of the patients with MMT in combined ABD and ER.

An upper quarter neurological examination was performed to screen each patient for symptoms of spinal origin. This included dermatomal, myotomal, and deep tendon reflex (DTRs) examination. Dermatomal testing assessed light touch sensory palpation to the upper extremities. Myotomal testing was assessed via MMT of the upper extremities. DTRs were assessed via testing of the C5, C6, and C7 nerve roots in bilaterally and were found to be normal in all patients. Radiculopathy testing included Spurling’s for radiculopathy (SP = .95, SN = .93, +LR = 18.6), Centralization for discogenic origin (SP = .94, SN = .40, +LR- 6.7), and Passive Accessory Intervertebral Movement (PAIVM) palpation for zygapophyseal joint pain syndromes (SP = .81, SN = .94, +LR = 4.9)65. There were no neurovascular or cervical syndrome abnormalities noted.

Special testing included tests for determining shoulder pain origin as proposed in a systematic review by Biederwolf.66 Biederwolf suggested that using the internal rotation manual muscle test (IRMMT) and external rotation manual muscle test (ERMNT) at 90 degrees abduction and 80 degrees external rotation can help determine if the shoulder pain origin is of RTC, intra-articular, or extra-articular origin. Special tests for ruling in/out a partial rotator cuff tear (PRTC) followed a recommended shoulder special test algorithm for clinical diagnostic accuracy. PRTC tear of the supraspinatus, infraspinatus, and teres minor were ruled out via the IRMMT < ERMNT and a negative External Rotation Lag Sign (SP = .98, SN = .69-.98, +LR = 15.5-34.5) and negative Hornblower’s Sign (SP = .93, SN = 1.0, +LR = 14.29). Subscapulis tears were ruled out with a negative internal rotation lag sign (SP = .96, SN = .97, +LR = 24.3).

Subacromial impingement syndrome (SAIS) was assessed via the Biederwolf cluster as follows: IRMMT > ERMNT, 1) Painful Arc Sign, 2) Hawkins-Kennedy Test, and 3) Infraspinatus MMT. If all of three of these tests are (+), there is a +LR= 5.03 and a post-test probability (PTP)= 95% (91% if 2/3 are positive). According to Park et al, the Painful Arc Sign is the most sensitive (73.5%) and the infraspinatus MMT was the most specific (90.1%).67 Internal impingement was ruled out with a (-) ERMNT > IRMMT and (-) Posterior Impingement Sign according to Biederwolf. If both of these tests are (+), there is a PTP nearing 100%, and if both are (-), there is a 2.5% chance of having internal impingement.

Labral pathology special testing lacks high quality clinical test clusters according to Hegedus et al, and according to Jones et al, thus superior labral anterior-posterior (SLAP) specific physical examination results cannot be used as the sole basis for a SLAP lesion diagnosis.68,69 Given this information, a newer combination of individual tests per Biederwolf was used to rule out SLAP pathology, and this combination included a (-) Biceps Load I Test (SP = .97, SN = .90, +LR = 30), and a (-) Biceps Load II Test (SP = .97, SN = .90, +LR = 30). According to Biederwolf, the psychometric properties of long head of the biceps (LHB) testing is not clinically useful, hence the author used palpation of the LHB to determine pain in this region. Partial RTC tears, subscapular tears, internal impingement, and SLAP tears were ruled out based on the examination results. A few of the patients were (+) for SAIS and all reported significant tenderness to palpation in the proximal biceps tendon region in the anterior shoulder. It was determined from the examination that the origin of all eight of the patients’ non-specific...
shoulder pain (NSSP), likely had a RTC (supraspinatus and/ or Infraspinatus/ Teres Minor) tendinopathy component based upon examination synthesis.

**CLINICAL IMPRESSION 2**

Based upon examination findings, all eight patients were deemed appropriate to receive the intervention described in the “Intervention” section of the case series. There were no contraindications that would preclude any of the eight patients from receiving DN with electrical stimulation and SE. All patients reported no previous limitations in sleep, lifting/ reaching, or general self-care function prior to the onset of their shoulder pain. All eight patients had ongoing shoulder pain affecting their daily activity tolerance and sought long-term pain relief, which they had not received with prior treatment. Progressive shoulder pain coupled with negative contraindications for DN intervention made the patients appropriate for DN to be performed.

**OUTCOME MEASURES**

The outcome measures used in this case series were the Visual Analog Scale (VAS) and the Quick DASH (QD), and are reported in Table 1 and Table 1a. The VAS is a 100 mm scale where the patient marked a line at the area most closely associated with their respective pain levels. At baseline, the mean VAS for “best, current, and worst” level scores was 22.5, 28.36, and 68.88 (out of 100) respectively. The VAS has moderate to good reliability (correlation coefficient 0.60-0.77) to detect disability and high reliability for pain (correlation coefficient 0.76-0.84). The minimal clinical significant change has been reported to be 11 points (mm) on a 100 point (mm) scale.70

The QD was used to assess functional disability. The higher the recorded score, the greater the disability the patient experienced. The QD is a quick and reliable patient self-report functional outcome tool that can be easily completed and demonstrates good test- retest reliability (0.90) and responsiveness in patients with shoulder pain.72 The minimal clinically important difference (MCID) was found to be 8 points, and the minimal detectable change (MDC) was found to be 11 points.72,73 At baseline, the mean QD score for all subjects was 43.09 points.

**INTERVENTION**

The patients were treated for one to two times per week for up to eight weeks, and no more than sixteen total treatment sessions. Patients were treated

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

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
<th>Subject 4</th>
<th>Subject 5</th>
<th>Subject 6</th>
<th>Subject 7</th>
<th>Subject 8</th>
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</thead>
<tbody>
<tr>
<td><strong>QD Initial</strong></td>
<td>68.18</td>
<td>90.0</td>
<td>25</td>
<td>28.36</td>
<td>21.15</td>
<td>50</td>
<td>18</td>
<td>43.09</td>
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<tr>
<td><strong>QD Final</strong></td>
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<td>47.72</td>
<td>15.90</td>
<td>0</td>
<td>0</td>
<td>4.50</td>
<td>0</td>
<td>26.09</td>
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<tr>
<td><strong>QD Follow Up</strong></td>
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<td>34.1</td>
<td>15.90</td>
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<td>0</td>
<td>6.81</td>
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<td>18.20</td>
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<td><strong>VAS (mm) Initial:</strong></td>
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<td>43</td>
<td>0</td>
<td>56</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<td>Best</td>
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<tr>
<td>Current</td>
<td>81</td>
<td>72</td>
<td>11</td>
<td>30</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>33</td>
</tr>
<tr>
<td>Worst</td>
<td>100</td>
<td>90</td>
<td>43</td>
<td>68</td>
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<td>73</td>
</tr>
<tr>
<td><strong>VAS (mm) Final:</strong></td>
<td>11</td>
<td>2</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Best</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Current</td>
<td>22</td>
<td>3</td>
<td>9</td>
<td>6</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>Worst</td>
<td>44</td>
<td>10</td>
<td>32</td>
<td>7</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td><strong>VAS (mm) Follow Up:</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<tr>
<td>Current</td>
<td>0</td>
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<td>4</td>
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<td>Worst</td>
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<td>7</td>
<td>15</td>
<td>3</td>
<td>3</td>
<td>40</td>
</tr>
</tbody>
</table>

QD= Quick DASH  
VAS= Visual Analog Scale
with a specific exercise protocol outlined in Appendix A and Table 2, and a five-point DN protocol to the involved shoulder focusing on pain mitigation. The SE protocol was prescribed based on exercises provided in two studies, which suggest evidence-based exercises for improving RTC, deltoid, and scapular strengthening important for optimal shoulder complex kinematics. Patients performed three sets of 15 repetitions for each exercise, with a weight that was reported by each patient to cause significant fatigue and muscular burning during the last three to four repetitions of each exercise. Resistance was provided in the form of hand weights (dumbbells) and an exercise cable machine.

During the DN intervention, patients were positioned seated in a chair with the involved upper extremity resting at their side and the hand on the thigh. The following structures were treated: (1) supraspinatus musculo-tendinous junction at the humeral head; (2) supraspinatus anterior and (3) posterior teno-osseous junctions on the greater tuberosity; (4) supraspinatus teno-osseous junction in the muscle belly at the supraspinous fossa; and (5) the deltoid teno-osseous insertion at the deltoid tuberosity. The location of the needles were determined based on the author’s DN training and clinical experience with the performance of DN for shoulder pain, and this has become a semi-standardized approach to the application of DN for this condition in the author’s private practice. Each patient performed the SE program exactly as listed in Table 2 prior to DN, without variation from one patient to the next.

The needles used in this case series were solid monofilament Seirin J-type sterile needles (Seirin Corp., 1007-1 Sodeshi-Cho, Shimizu-ku, Shizuoka-shi, Shizuoka 424-0036 Japan), 0.30 diameter (DIA) x 50 mm. and 0.25 DIA x 30 mm. Needles were held in the therapist's dominant hand for application and manipulation of the needle within the tissue. Before needle insertion, an application of 70% isopropyl alcohol was performed to the areas and allowed to dry for a least ten-seconds, which reduces the resident micro-flora of the skin by 80-91%. All DN interventions were performed according to the Dry Needling Institute (DNI) of the American Academy of Manipulative Therapy (AAMT) Fellowship training program. Periosteal pecking to the humerus in various teno-osseous regions was used to attempt to elicit pain relief at the RTC and deltoid attachments throughout the shoulder complex. The electrical stimulation unit used to apply current to the needles was an AWQ-104L digital electro-acupunctoscope, four-channel, eight-lead device (Lahasa OMS, 230 Libbey Parkway, Weymouth, MA 02189). The use of electrical stimulation applied to the needles was performed according to the following parameters outlined by the DNI: 2 Hz, 250 microseconds, running continuously for twenty minutes in the form of an asymmetric biphasic square wave at an intensity described by the patients as “mild to moderate”. Call bells were left with each patient receiving DN.

Needle insertion points are described in Figure 1 and shown in Figure 2. Manual needle manipulation was utilized after needle insertion, including periosteal pecking and clockwise needle winding. After 10 “periosteal pecks” at bony attachments, the needles were wound clockwise to attain needle grasp between the needle and soft tissue, and left in-situ for 20 minutes.

### OUTCOMES

The demographic characteristics of the patients are outlined in Table 3. All patients subjectively reported improvements in sleep. The efficacy of DN was

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Mean for 8 Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>QD Initial</td>
<td>43.09</td>
</tr>
<tr>
<td>QD Final</td>
<td>16.04</td>
</tr>
<tr>
<td>QD Follow Up</td>
<td>6.59</td>
</tr>
<tr>
<td>VAS (mm) Initial:</td>
<td></td>
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<tr>
<td>Best</td>
<td>22.5</td>
</tr>
<tr>
<td>Current</td>
<td>28.36</td>
</tr>
<tr>
<td>Worst</td>
<td>68.88</td>
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<tr>
<td>VAS (mm) Final:</td>
<td></td>
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<tr>
<td>Best</td>
<td>2.36</td>
</tr>
<tr>
<td>Current</td>
<td>5</td>
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<tr>
<td>Worst</td>
<td>13.25</td>
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<tr>
<td>VAS (mm) Follow Up:</td>
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</tr>
<tr>
<td>Best</td>
<td>0.36</td>
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<tr>
<td>Current</td>
<td>4.88</td>
</tr>
<tr>
<td>Worst</td>
<td>17.88</td>
</tr>
</tbody>
</table>

QD= Quick DASH
VAS= Visual Analog Scale
assessed by pain response(s), MMT improvement, disability level as reported by the QD, and through subjective reports of improvement in the patient’s general daily activity and sleep tolerance. At baseline and upon completion of the intervention, pain and disability were assessed via the VAS and QD outcome measures. Strength of the abductors and external rotators in all eight patients improved to 5/5. The results of these outcome measures are shown in Table 1. Means of the outcome measure scores were used to measure the overall improvement in pain and disability levels, as this gives a general representation of improvement between the eight patients. Each patient met the MCID and MDC for the QD as shown in Table 1. The final QD scores upon completion of the intervention ranged from 0 to 47.72 points versus the initial range of 18 to 90.9 points. The mean improvement between the eight patients demonstrated a mean improvement from 43.09 at baseline to 16.04 at completion of treatment, which is well above the MDC/MDIC indicating clinically meaningful improvement. At long term follow up, obtained by calling the patients during preparation of the case series (average of 8.75 months after completion of the treatment sessions); the QD average score was 6.59.

The VAS scores were broken down into reported best (VASB), current (VASC), and worst (VASW) levels. Individual VAS ranges were as follows: VASB at baseline, scores ranged from 0 mm to 81 mm and improved to a range of 0 mm to 11 mm at completion of treatment. The VASC ranged from 0 mm to 81 mm and improved to 0 mm to 22 mm upon completion. The VASW scores at baseline ranged from 43 mm to 100 mm and improved to 0 mm to 44 mm upon completion. Means were then calculated to average the eight patient’s raw scores for ease of interpretation. The mean VASB score improved from 22.5 mm to 2.36 mm (at completion of treatment). The mean VASC improved from 28.36 mm to 5.0 mm. The mean VASW improved from 68.88 mm to 13.255 mm.

<table>
<thead>
<tr>
<th>Table 2. Strengthening Exercise Protocol</th>
</tr>
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<tr>
<td>Variable</td>
</tr>
<tr>
<td>----------------------------</td>
</tr>
<tr>
<td>Strengthening Exercise Activities</td>
</tr>
<tr>
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</tbody>
</table>

ER= external rotation; ABD= abduction; FLEX= flexion; IR= internal rotation; EXT= extension
DISCUSSION

Clinical results were positive, indicating improvements in pain and disability per the outcome measures used in this retrospective case series. Patient reports of improved sleep, reaching/lifting ability, and general self-care activity tolerance was also reported at follow up. All patients demonstrated improvements strength, which allowed them to return to independent exercise activities without limitation from shoulder pain, where a lack of ability to exercise was a common report prior to intervention.

Justification for DN to tendinous junctions, was supported by the following concepts: poor tendon vascularization, vessel anastomosis at the tendon-bone, and grafted tendons becoming histologically identical to the original tendon. DN techniques such as needle winding may have a local and/or remote therapeutic effect based on mechanical coupling of connective tissue and the needle, thereby causing a "downstream" pain modulating effect (from the central nervous system to the periphery) on the generation of a mechanical signal caused by needle grasp pulling. These downstream effects may include cell secretion, modification of extracellular matrix, enlargement and propagation of the pain signal along connective tissue planes, and afferent input modulation by changes in the connective milieu.

Considering the idea that the supraspinatus has a specific devascularized region, and the vascular supply to tendons has been demonstrated to arise from multiple structures, implications for DN to the tendinous regions of RTC structures appears to be a legitimate area for further investigation.

It should be noted that studies comparing the use of DN with and without electrical stimulation should be performed in the future, as there are no current studies examining DN alone vs. DN with electrical stimulation in the treatment of chronic RTC tendinopathy. There is a good deal of evidence for the use of electrical "acupuncture" in the literature, but minimal evidence for DN alone without the use of electrical stimulation, hence, the author's clinical experience determined the use of electrical stimulation to be an effective adjunct to dry needling. There is also a lack of quality evidence to support specific exercise protocol for the rehabilitation of this condition, so the use of an evidenced-based exercise pro-

<table>
<thead>
<tr>
<th>Needle Number</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5 fingerbreadths medial to the medial acromial border angled inferior and slightly laterally.</td>
</tr>
<tr>
<td>2</td>
<td>Anterior &quot;eye&quot; dimple on the greater tuberosity (found by ABD the shoulder to 90 degrees).</td>
</tr>
<tr>
<td>3</td>
<td>Posterior &quot;eye&quot; dimple on the greater tuberosity (found by ABD the shoulder to 90 degrees).</td>
</tr>
<tr>
<td>4</td>
<td>1 fingerbreadth superior to the midpoint scapular spine angled inferior and posterior.</td>
</tr>
<tr>
<td>5</td>
<td>Deltoid tuberosity attachment on the Humerus.</td>
</tr>
</tbody>
</table>

At follow up, the mean VAS was 0.36 mm, the mean VAS was 4.888 mm, and the mean VAS was 17.88 mm. All eight patients verbally reported subjective reports of improved sleep, significantly less pain with activities such as grabbing a gallon of milk from the refrigerator, and general improved tolerance to daily activities such as self care/dressing activities upon completion of treatment, and at the follow-up. Sleep, lifting/reaching, and general self-care activity limitation was noted as limited prior to initiation of treatment. At the long-term follow up, there were no significant reports of functional limitations reported by any of the eight patients.
for shoulder pain, and this may be another area of research from a manual therapy approach to include with DN.80-89 Another area of further research should also compare the use of DN with electrical stimulation versus DN alone.

**CONCLUSIONS**

SE and DN were tolerated well by the patients, demonstrating improvements in pain and function, without significant adverse effects. Given the clinically meaningful reduction in pain and improvements in reported function, the addition of DN to SE for NSSP etiologies shows promise. Future higher-level research is needed to fully explore the effectiveness of DN for chronic RTC tendinopathies when compared to traditional interventions.

**REFERENCES**


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80. Bergman GJ, Winters JC, Groenier KH, et al. Manipulative therapy in addition to usual medical care for patients with shoulder dysfunction and pain:


## APPENDIX A

### Images of SE activities

<table>
<thead>
<tr>
<th>Exercise Description</th>
<th>Image</th>
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<td>Side-lying ER w/ Towel Roll</td>
<td><img src="image1.jpg" alt="Image" /></td>
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<tr>
<td>Supine Serratus Punch</td>
<td><img src="image2.jpg" alt="Image" /></td>
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<tr>
<td>Prone Horiz. Shoulder ABD at 100° FLEX &amp; 10° ER. (Y’s)</td>
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<tr>
<td>Standing Shoulder FLEX (I’s) with 10° ER</td>
<td><img src="image4.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Standing Shoulder ABD (T’s) with 10° ER</td>
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</tr>
<tr>
<td>Standing Full Can (V’s) with 10° ER</td>
<td><img src="image6.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Standing Machine Shoulder EXT 90-0</td>
<td><img src="image7.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Standing Machine Rowing</td>
<td><img src="image8.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Machine IR at 20° ABD</td>
<td><img src="image9.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Machine ER at 20° ABD</td>
<td><img src="image10.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Machine D1 FLEX &amp; EXT</td>
<td><img src="image11.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Machine D2 FLEX &amp; EXT</td>
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</table>
ABSTRACT

Background: The incidence of patellar subluxation or dislocation has been documented up to 43/100,000 with females more prevalent than males. There are many contributing factors involving the hip, knee, and ankle that lead to patellar subluxation. A patellar position of lateral tilt with lateral glide may indicate weakness of the vastus medialis oblique (VMO) and adductors, increased tightness in the iliotibial band, and overpowering of the vastus lateralis. Patella alta can predispose an individual to lateral dislocation due to the patella placement outside of the femoral trochlear groove with a disadvantage of boney stability. Other factors that may cause the patella to laterally sublux or dislocate during a functional activity or sporting activity include a position of femoral external rotation, tibial internal rotation, and excessive contraction of the vastus lateralis. The medial patellofemoral ligament (MPFL) aids in the prevention of a lateral patellar subluxation or dislocation. In cases where there is recurrent subluxation/dislocation and Magnetic Resonance Imaging confirms a MPFL tear, a reconstruction may be the treatment of choice.

Purpose: The purpose of this case series is to describe the post-surgical physical therapy management of MPFL reconstructions, outcomes using the Modified Cincinnati Knee Outcome Measure (MCKOM) and to propose staged physical therapy interventions for this pathology in the form of a treatment progression.

Methods: Post-operative management data and outcomes were retrospectively collected using a detailed chart review methodology from seven subjects who underwent MPFL reconstruction.

Findings: The Modified Cincinnati Knee Outcome Measure (MCKOM) was analyzed for each participant in four sections that were most important to the return and maintenance of participation in sport. At follow-up the mean scores for the seven subjects in Section 3 (instability) was 19.3/20, Section 4 (overall activity level) was 17.3/20, Section 7 (running activity) was 4.5/5, and Section 8 (jumping and twisting) was 4.3/5. Overall all subjects scored over an 80 which indicated excellent results for return to activity/sport.

Conclusions: In this case series, seven subjects after MPFL reconstruction returned to sport or functional activity following a physical therapy treatment progression including proprioceptive-focused, and dynamic rehabilitation, along with a home exercise program. Based on these positive results and a review of relevant literature regarding MPFL rehabilitation, a rehabilitation progression was presented.

Level of Evidence: Level 4- Case Series

Keywords: Lateral patellar subluxation, medial patellofemoral ligament reconstruction, Modified Cincinnati Knee Outcome Measure.
INTRODUCTION

Patellar subluxation or dislocation can lead to recurrent disability, time away from functional activity, and sports participation. The rate of patellar subluxation/dislocation has been documented up to 43/100,000 with reported rates greater in the female population. There are many contributing factors involving the hip, knee, and ankle that may lead to patellar subluxation. A patellar position of lateral tilt with lateral glide may indicate weakness of the vastus medialis oblique (VMO) and adductors, increased tightness in the iliotibial band, and an imbalance of the vastus lateralis over the medialis. Patella alta can predispose an individual to lateral dislocation due to the patella placement superior to the femoral trochlear groove with a subsequent loss of bony stability. Other factors that may cause the patella to laterally sublux or dislocate during a functional activity or sporting activity include a position of femoral external rotation, tibial internal rotation, and excessive contraction of the vastus lateralis.

The bony contribution to stability comes from the patella being engaged in the track of the trochlea at the distal femur. The lateral trochlea of the femur is elevated with regard to the medial trochlea, in order to help resist lateral forces. Bony stability is most relevant between the ranges of 20 and 60 degrees of knee flexion. In the range of 0-20 degrees, in which the patella dislocates the most, the soft tissue restraints including the medial patellofemoral ligament (MPFL) are responsible for preventing lateral patellar subluxation or dislocation. During the 0-20 degree flexion range, the patella is in essence, floating, and not engaged in the bony groove. From 0-20 degrees, the MPFL is the primary ligament that provides 60% restraint to lateral patellar subluxation. The VMO dynamically aids the static stabilizer: the MPFL. The MPFL is in the second layer on the medial side of the knee, deep and distal to the insertion of the VMO. It originates superior posterior to medial femoral epicondyle, one centimeter distal to the adductor tubercle and close to the distal femoral growth plate. It also houses the adductor magnus, fibers of the medial collateral ligament (MCL), and the posteromedial capsule. The MPFL forms an arch with the superficial MCL and inserts laterally on the proximal two thirds of the medial patella. Some of the deep fibers also attach to the VMO.

When repeated dislocations occur, the patient is typically sent for Magnetic Resonance Imaging (MRI) assessment. This assessment will determine if the medial patello femoral ligament is torn and if surgery is necessary. Panni et al suggest that MRI is the most accurate way to diagnose MPFL injury and found that a MPFL reconstruction would be more reliable than a repair. Smith et al published a meta-analysis regarding the differences in operative and nonoperative management after patellar dislocation. They found that there was a higher rate of recurrent patellar subluxation when dislocations were treated non-operatively.

Several different surgical procedures have been discussed in the literature. Sampatakos and Getelman described the use of the semitendinosus allograft, the tensile strength of which is just over 200 N. The double bundle technique may aid in more completely correcting the original anatomy of the MPFL by decreasing patellar rotation and thereby improving its stability. Deie et al concluded that reconstruction of the MPFL using a semitendinosus graft was successful in three children (6-10 years of age) who had experienced repeated subluxation/dislocation. Galeazee and Baker also described good to excellent results in 81% of 53 knees with a recurrence rate of 5%. Aulia et al stated that other authors described 62%-82% excellent or good results in over 50 cases, with 8% reporting dislocation. They go on to suggest that the procedure can resolve dislocation and provide satisfactory patellofemoral congruence evidenced by a static Computerized Tomography (CT) scan.

After surgery is performed, physical therapy is indicated. Mikashima et al discussed their post-operative course where patients were placed in a post-surgical knee immobilizer, began quadriceps isometric exercise initiated as tolerated, and passive range of motion (PROM) on day two. Immobilization in full extension continued for three weeks, full weight bearing was initiated at five weeks, jogging and mild sports activity at four months, and full return to sport at six months. The majority of their patients returned to previous sporting level based on their clinical findings.

Menetrey, Putman, and Gard discussed criteria for return to sport after patellar dislocation or following surgery. Their definition of post operative patient...
success was when patients experienced no early re-injury, no residual pain, and demonstrated the ability to participate in sport after a five year period. Key factors in their rehabilitation program included clinical examination (assessment of the amount of laxity), strength development, especially the of the quadriceps and gluteus medius, development of neuromuscular control, performance of sport specific drills, and proper counseling between all members of the athlete’s team. However, these authors noted that there is limited literature regarding the return to sport after such procedures. Therefore, this retrospective descriptive case series will investigate rehabilitation principles for post-surgical physical therapy treatment following MPFL reconstruction after multiple lateral patellar subluxations or dislocations.

The purpose of this case series is to describe the post-surgical physical therapy management of MPFL reconstructions, outcomes using the Modified Cincinnati Knee Outcome Measure (MCKOM), and to propose staged physical therapy interventions for this pathology in the form of a treatment progression. The authors’ hypothesis was that surgical reconstruction of the MPFL and post-operative physical therapy leads to excellent outcomes and safe return to sport or functional activity.

METHODS

Participants
This case series included two male and five female subjects, 14 to 35 years of age. All of the patients underwent MPFL reconstruction using autologous semitendinosus graft due to recurrent dislocation, had failed rehab prior to surgery, and had a confirmed tear of the MPFL on MRI. Subjects were excluded if they had undergone prior patellar surgery for MPFL reconstruction or other patellar realignment procedures.

Seven subjects consented to anonymous utilization of data gleaned from a detailed chart review of their physical therapy care. The subjects in this case series each underwent a MPFL reconstruction with a semitendinosus autograft from the ipsilateral side. IRB approval was granted and the rights of the subjects were protected. After consent to participate and following the completion of physical therapy, they were asked to fill out a Modified Cincinnati Knee Score any time from 28 to 200 weeks after discharge.

Procedure
Data were obtained through a detailed chart review of the subject’s physical therapy treatment starting with the initial evaluation, progress notes, reevaluations, and discharges available via the Redoc 7.8 documentation note writing system. The clinical findings of importance were range of motion (ROM), strength, weight bearing status, bracing, and exercise progression which included proprioceptive activity. Other outcomes taken into consideration included timeframes and interventions related to dynamic proprioception, running, plyometrics, sport specific drills, and return to functional activity/sport participation. The physical therapy interventions for each of the subjects were performed by the physical therapy staff. The MCKOM score was used for the follow up outcome measure scores.

RESULTS

Table 1 displays demographics including; diagnosis, age, and gender of the included subjects, spanning 14 to 35 years of age.

Range of motion achievements are reported in Table 2 and were taken according to methods described by Norkin and White using a Baseline goniometer. Mean range of motion achievements for all subjects are displayed in Chart 1.

The immobilization and bracing progressions reported in Table 3 were dependent on the allowance of the referring physician.

The progression of weight bearing status is presented in Table 4, which was based upon physician instruction and patient ability to fully weight bear on the involved extremity without loss of control of

<table>
<thead>
<tr>
<th>Table 1. Surgical Subjects Demographics</th>
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<tbody>
<tr>
<td>Diagnosis</td>
</tr>
<tr>
<td>MPFL Reconstruction</td>
</tr>
<tr>
<td>MPFL Reconstruction</td>
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<td>MPFL Reconstruction</td>
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</tr>
<tr>
<td>MPFL Reconstruction</td>
</tr>
<tr>
<td>Summary</td>
</tr>
</tbody>
</table>
the knee during a normal gait pattern. The physicians for each of the surgical cases provided therapists with guidelines for their MPFL patients.20, 21

The descriptions regarding non-weight bearing exercises to advanced strengthening program are noted in Table 5 and means for all subjects are presented in Chart 2.

---

**Table 2. Surgical Time Line for achievement of Range of Motion in Weeks.**

<table>
<thead>
<tr>
<th>Surgical</th>
<th>Weeks to Obtain Full Extension</th>
<th>Progression of Flexion ROM *Weeks from initial surgery date</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>4</td>
<td>30° 60° 90° 120° &gt;120°</td>
</tr>
<tr>
<td>S2</td>
<td>2</td>
<td>4 6 11 13</td>
</tr>
<tr>
<td>S3</td>
<td>2</td>
<td>2 3 4 9 11</td>
</tr>
<tr>
<td>S4</td>
<td>2</td>
<td>2 4 8 10 11</td>
</tr>
<tr>
<td>S5</td>
<td>2</td>
<td>2 3 5 15</td>
</tr>
<tr>
<td>S6</td>
<td>2</td>
<td>2 3 7 9 10</td>
</tr>
<tr>
<td>S7</td>
<td>4</td>
<td>3 4 9 10</td>
</tr>
<tr>
<td>Time range (weeks)</td>
<td>2-4</td>
<td>3-8 5-11 10-17</td>
</tr>
<tr>
<td>Average (weeks)</td>
<td>2.3</td>
<td>3.5 5.4 8.8 12.4</td>
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**Table 3. Surgical Length of Time for Bledsoe to be Unlocked to 30 degrees in Weeks from Initial Injury Date**

<table>
<thead>
<tr>
<th>Surgical</th>
<th>Locked Bledsoe (Brace) Surgical</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>6</td>
</tr>
<tr>
<td>S2</td>
<td>3</td>
</tr>
<tr>
<td>S3</td>
<td>4</td>
</tr>
<tr>
<td>S4</td>
<td>3</td>
</tr>
<tr>
<td>S5</td>
<td>3</td>
</tr>
<tr>
<td>S6</td>
<td>4</td>
</tr>
<tr>
<td>S7</td>
<td>4</td>
</tr>
<tr>
<td>Time range (weeks)</td>
<td>3-6</td>
</tr>
<tr>
<td>Average (weeks)</td>
<td>3.9</td>
</tr>
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**Table 4. Surgical Weight Bearing Status in Weeks from Surgery to Full Weight Bearing**

<table>
<thead>
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<th>FWB</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>4</td>
</tr>
<tr>
<td>S2</td>
<td>10</td>
</tr>
<tr>
<td>S3</td>
<td>6</td>
</tr>
<tr>
<td>S4</td>
<td>6</td>
</tr>
<tr>
<td>S5</td>
<td>3</td>
</tr>
<tr>
<td>S6</td>
<td>6</td>
</tr>
<tr>
<td>S7</td>
<td>6</td>
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<tr>
<td>Time range (weeks)</td>
<td>4-10</td>
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<td>Average (weeks)</td>
<td>5.9</td>
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**Table 5. Length of Time for Transition from Table Exercises to Advanced Strengthening Exercises, in Weeks from Surgery**

<table>
<thead>
<tr>
<th>Surgical</th>
<th>NWB Exercises</th>
<th>Adductor Strengthening</th>
<th>Advanced Strengthening Exercises</th>
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</thead>
<tbody>
<tr>
<td>S1</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>S2</td>
<td>2</td>
<td>3</td>
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</tr>
<tr>
<td>S3</td>
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<td>5</td>
<td>4</td>
</tr>
<tr>
<td>S4</td>
<td>2</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>S5</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>S6</td>
<td>2</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>S7</td>
<td>2</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Time range (weeks)</td>
<td>2-4</td>
<td>3-7 3-5</td>
<td></td>
</tr>
<tr>
<td>Average (weeks)</td>
<td>2.3</td>
<td>4.3 4.4</td>
<td></td>
</tr>
</tbody>
</table>

NWB= non weight bearing.
The timelines for return to sport or functional activity are outlined in Table 6, which lays out the progression from static to dynamic proprioceptive activity, running, plyometrics, sport specific drills, and return to a sport or functional activity.

The follow up MCKOM scores are displayed in Table 7. The physical therapists progressed each patient's program based on changes in ROM, contraction of the quadriceps muscle, assessment of gliding of the patella superiorly, and the ability to perform a straight leg raise without an extensor lag. Previous literature has suggested that the firing of the adductor muscle may aide in the recruitment of the VMO secondary to the MPFL being housed with the adductor muscle in the anatomical second layer of the knee. Tables 8, 9, and 10 review the timeline for return running, jumping, and return to sport with the follow up data from the MCKOMS.

Table 6. Timeline for Return to Sport/Full Functional Activity

<table>
<thead>
<tr>
<th>Weeks from Surgery</th>
<th>Stage I</th>
<th>Stage II</th>
<th>Stage III</th>
<th>Stage IV</th>
<th>Stage V</th>
<th>Stage VI</th>
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<tr>
<td>1</td>
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<td>6</td>
<td>9</td>
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<tr>
<td>2</td>
<td>S2</td>
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<td>16</td>
<td>16</td>
<td>24</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>S3</td>
<td>8</td>
<td>16</td>
<td>16</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>4</td>
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<tr>
<td>5</td>
<td>S5</td>
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<td>10</td>
<td>15</td>
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<tr>
<td>6</td>
<td>S6</td>
<td>10</td>
<td>20</td>
<td>21</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>7</td>
<td>S7</td>
<td>7</td>
<td>16</td>
<td>20</td>
<td>23*</td>
<td></td>
</tr>
<tr>
<td>Time frame (wks)</td>
<td>6-12</td>
<td>6-20</td>
<td>10-21</td>
<td>13-24</td>
<td>14-19</td>
<td>19-36</td>
</tr>
<tr>
<td>Average (wks)</td>
<td>7.85</td>
<td>12.4</td>
<td>16.3</td>
<td>19.6</td>
<td>17.3</td>
<td>27</td>
</tr>
</tbody>
</table>

* = subject dislocated opposite knee during post-rehab during work, therefore unable to progress to next stage until healed and returned from college (130 weeks)

Participants' scores on the MCKOM reflect the outcome post rehabilitation in regards to return to function. Participants each returned to their prior sport or activity demands without instability or reoccurrence. Participant S1 returned to track, S2 was a

Figure 1. Straight leg raise (NWB exercise).

Figure 2. Adductor squeezes (Adductor Strengthening). A. Isometrically in hooklying. B. During leg press.

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Table 6. *Stage Definitions with Associated Exercises*

<table>
<thead>
<tr>
<th>Stage</th>
<th>Definition</th>
<th>Exercises</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage I Proprioception</td>
<td>Static wobble board, dynadisc, single leg cone touch (Figure 3), bilateral to unilateral weight bearing (Figure 8)</td>
<td></td>
</tr>
<tr>
<td>Stage II Dynamic Proprioceptive</td>
<td>Agility drills (shuffle, two step with circles), single limb squat, BOSU squats (Figure 4), single hopping in place (Figure 10)</td>
<td></td>
</tr>
<tr>
<td>Stage III Running</td>
<td>Progress speed as tolerated, cone drills</td>
<td></td>
</tr>
<tr>
<td>Stage IV Plyometrics</td>
<td>Jumping boxes (Figure 6), jump and squat, hop and squat, lateral jump, single leg box jump (Figure 9)</td>
<td></td>
</tr>
<tr>
<td>Stage V Sport Specific Drills</td>
<td>Cutting (Figure 5), pivoting, activity based on sport (Figure 7)</td>
<td></td>
</tr>
<tr>
<td>Stage VI Return to Sport</td>
<td>Defined as the week that they returned to sport</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3. *Single Leg Stance with forward cone touch*

Figure 4. *Dynamic Proprioception on BOSU™*

Figure 5. *Running and cutting drills*

domestic engineer, S3 and S7 returned to fitness that consisted of cross training, endurance training, and weight training, S5 returned to Judo, and S6 returned to kickline. Information for participant S4 was lost to follow up. The comparison between the point at which the participants reached Stage III (running) (Table 9) and his/her function at follow up exemplifies the success of the guideline in returning the participants to prior activity or level of function.

When assessing the effectiveness of the rehabilitation guideline and return to activity, in Table 11, Sections 3, 4, 7, and 8 of the MCKOM were analyzed
for all participants because each section examines a different facet of activity at follow up. Section 3 considered the participants regarding instability. Eighty-three point three percent of participants that responded answered in the top category (20 points) indicating excellent outcome and the other 16.6% in the very good outcome (16 points) regarding the affected knee giving way at follow up.
Table 7. Knee Outcome Measure Scores (MCKOM) Follow up Date

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Score Totals (MCKOM)</th>
<th>Follow up Timeline (weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>S2</td>
<td>90</td>
<td>30</td>
</tr>
<tr>
<td>S3</td>
<td>100</td>
<td>28</td>
</tr>
<tr>
<td>S4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S5</td>
<td>100</td>
<td>104</td>
</tr>
<tr>
<td>S6</td>
<td>82</td>
<td>70</td>
</tr>
<tr>
<td>S7</td>
<td>83</td>
<td>78</td>
</tr>
</tbody>
</table>

Table 8. Timeline for Return to Running

<table>
<thead>
<tr>
<th>Subject Number</th>
<th>Stage III</th>
<th>Follow Up (weeks) MCKOMS Section?</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>10</td>
<td>200</td>
</tr>
<tr>
<td>S2</td>
<td>16</td>
<td>30</td>
</tr>
<tr>
<td>S3</td>
<td>16</td>
<td>28</td>
</tr>
<tr>
<td>S4</td>
<td>Lost to follow up</td>
<td>Lost to follow up</td>
</tr>
<tr>
<td>S5</td>
<td>15</td>
<td>104</td>
</tr>
<tr>
<td>S6</td>
<td>20</td>
<td>70</td>
</tr>
<tr>
<td>S7</td>
<td>21</td>
<td>78</td>
</tr>
</tbody>
</table>

Table 9. Timeline for Return to Jumping

<table>
<thead>
<tr>
<th>Subject Number</th>
<th>Stage IV</th>
<th>Follow Up (weeks) MCKOMS Section 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>13</td>
<td>200</td>
</tr>
<tr>
<td>S2</td>
<td>24</td>
<td>30</td>
</tr>
<tr>
<td>S3</td>
<td>19</td>
<td>28</td>
</tr>
<tr>
<td>S4</td>
<td>Lost to follow up</td>
<td>Lost to follow up</td>
</tr>
<tr>
<td>S5</td>
<td>Not Documented</td>
<td>104</td>
</tr>
<tr>
<td>S6</td>
<td>19</td>
<td>70</td>
</tr>
<tr>
<td>S7</td>
<td>23</td>
<td>78</td>
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</tbody>
</table>

Table 10. Timeline for Return to Sport

<table>
<thead>
<tr>
<th>Subject Number</th>
<th>Stage VI</th>
<th>Follow Up (weeks) MCKOMS Section 4</th>
</tr>
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<tbody>
<tr>
<td>S1</td>
<td>36</td>
<td>200</td>
</tr>
<tr>
<td>S2</td>
<td>Discharged prior</td>
<td>30</td>
</tr>
<tr>
<td>S3</td>
<td>26</td>
<td>28</td>
</tr>
<tr>
<td>S4</td>
<td>Lost to follow up</td>
<td>Lost to follow up</td>
</tr>
<tr>
<td>S5</td>
<td>Not Documented</td>
<td>104</td>
</tr>
<tr>
<td>S6</td>
<td>19</td>
<td>70</td>
</tr>
<tr>
<td>S7</td>
<td>23</td>
<td>78</td>
</tr>
</tbody>
</table>

Table 11. Surgical Knee Outcome Measure Scores Breakdown (MCKOM)

<table>
<thead>
<tr>
<th>Surgical Knee Outcome Measure Scores</th>
<th>Section Score Totals</th>
<th>Total Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track</td>
<td>20 20 5 5</td>
<td>100</td>
</tr>
<tr>
<td>Domestic Engineer</td>
<td>20 16 4 4</td>
<td>82</td>
</tr>
<tr>
<td>Fitness activities: gym</td>
<td>20 20 5 5</td>
<td>100</td>
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<tr>
<td>Lost to Follow Up</td>
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<td></td>
</tr>
<tr>
<td>Judo</td>
<td>20 20 5 5</td>
<td>100</td>
</tr>
<tr>
<td>Kickline</td>
<td>16 16 4 4</td>
<td>82</td>
</tr>
<tr>
<td>Cross Training</td>
<td>20 12 4 3</td>
<td>83</td>
</tr>
</tbody>
</table>

Section 4 of the MCKOM, considered overall activity level, which is important to compare to the time at which the participants returned to sport/functional activity (Stage VI, seen in Table 6). Participant S1 reached stage VI at week 36 and maintained ability at follow up 200 weeks later. Participant S2 did not reach full function during physical therapy but at week 30 performed her usual functional activity.
reconstruction of the MPFL and post-operative physical therapy leads to excellent outcomes and safe return to sport or functional activity. Seven subjects who had sustained repeated lateral patellar subluxations, failed previous conservative physical therapy, and underwent the MPFL reconstruction were considered for this study. All subjects were treated using a semitendinosus autograft. Ladennauf, Berker, and stated that the “graft length is estimated by measuring the distance of the medial border of the reduced patella to the femoral insertion site, adding a total of 25 to 30 mm of length to allow the graft to be fixed within the bony sockets at each end.”10 This is very important during rehabilitation because the femoral insertion site is near the adductor tubercle and is tensioned at 30 degrees of knee flexion. For patients with an open growth plate, a guide wire was placed distal to the femoral growth plate.16 The range between 20 and 30 degrees of knee flexion is where the graft receives its tension so that the patella engages correctly in the trochlear sulcus.15,24,27 A double limb graft is used9 and two tenodesis screws fixate it to the patella with the knee in 30 degrees of flexion, attempting to decrease risk of disturbance to the growth plate.5, 10, 16 Due to the complexity of the surgery and the fixation, the surgeons supplied the therapist with guidelines for physical therapy.20, 21 Individualized alterations in progression of physical therapy care occurred based on the patient’s response to surgery and the judgment of the physical therapist.

The progression of flexion ROM from 30 to 60 degrees took three to four weeks. For greater than 120 degrees of flexion to be achieved, 10 to 17 weeks was required. Difficulty in obtaining flexion appeared related to pain secondary to the surgery. The pain was reported in the posterior medial aspect of the knee, occurring especially during flexion. This finding was noted by Shah and Howard et al who discussed that the drilling of the adductor tubercle and harvesting the medial hamstring graft could lead to pain during knee flexion. They showed that 13.4 % of their patients had this potential complication after MPFL surgery. All of the patients in their study had full knee extension.6 Six subjects in this case series demonstrated full extension on their first visit and by the second visit the last subject gained full extension.

DISCUSSION
The purpose of this case series is to describe the post-surgical physical therapy management of MPFL reconstructions, outcomes using the Modified Cincinnati Knee Outcome Measure (MCKOM) and to propose staged physical therapy interventions for this pathology in the form of a treatment progression. The authors' hypothesis was that surgical reconstruction of the MPFL and post-operative physical therapy leads to excellent outcomes and safe return to sport or functional activity.
review of treatment after lateral patellar dislocation. However, they also suggested that the vastus lateralis may overpower the VMO contributing to a lateral glide of the patella. The hypothesis for use of the adductors is their contribution to overall stability and the potential for improved anatomic position of the patella. Anatomically, the MPFL is connected to the VMO and adductors, specifically. This anatomic finding led the authors to implement strengthening of the adductors in order to impact recruitment of the VMO for improved dynamic medial stability of the patella. Although adductor strengthening began in the three to seven week timeframe, it should be noted that this muscle group may take longer than other groups to become pain free during isometric exercise due to the drilling of the adductor tubercle for the placement of the graft.

Advanced strengthening exercises were initiated between three and five weeks post-operatively, with the majority (4/7) of the subjects taking up to five weeks to perform upright, weight bearing activity due to the weakness of the knee extensors. This advancement in the exercise program correlated with reports of decreased pain, edema, improved ROM, their weight bearing status, and the ability to stand without buckling of the knee. Other considerations for delaying exercise progression include poor recruitment of the lower extremity muscular system.

Proprioceptive and neuromuscular control exercise progression is crucial after this procedure. In order to perform proprioceptive exercises adequate ROM, strength, low pain with activity, appropriate weight bearing status, and acceptable postural ability is required. Subjects in this case series completed non-weight bearing exercises, adductor strengthening exercises, and advanced strengthening exercises prior to beginning weight bearing proprioceptive exercise. Each of the previously mentioned factors must be present in order for a full retraining progression to affect the proprioceptive neurological system. Static demand proprioception was initiated between six and 12 weeks. The progression to dynamic proprioception occurred between seven and 20 weeks. Progression of the treatment program including modified running occurred between 10 to 21 weeks.
that responded was 92.8 %, demonstrating excellent results.\textsuperscript{14, 27}

**LIMITATIONS**

This retrospective case series describes how patients progressed to return to sport after undergoing a MPFL reconstruction; however there are a few limitations. This research study is limited in regards to its design in that the collection of data was done after the completion of treatments. It has a small sample size and a limited age range (14-35 years old) decreasing the generalizability to ages outside of this range. This study also lacks random selection secondary to the use of volunteers that attended a specific outpatient clinic. From the seven surgical patients, physical therapy was discontinued early for two of the patients. One patient returned to school after seven weeks but reached Stage II and the other patient, who reached stage III, had an insurance denial after 15 weeks. Subject 7 reached stage IV at 23 weeks, but then had a complication of a lateral patellar dislocation on the opposite knee. This patient's care had to be altered, as he also left for school and was seen for a follow up at 130 weeks with the ability to perform stage V and VI at that time. Future studies should attempt to conduct a randomized control trial comparing MPFL reconstruction surgeries to conservative physical therapy approach.

**CONCLUSION**

The results of this case series suggest that in seven subjects who subluxed or dislocated multiple times, and underwent MPFL reconstruction and progressive rehabilitation return to sport or functional activity with less instability was achieved as reported via the MCKOMS. The hypothesis, that surgical reconstruction of the MPFL would lead to good to excellent outcomes and safe return to sport or activity after physical therapy was confirmed. The subjects responses to return to sport or activity after physical therapy treatment was assessed using several scales within the MCKOMS and these scales might be helpful in evaluation of subjects after MPFL reconstruction.

The provided rehabilitation progression may be helpful to clinicians when designing a physical therapy progression for like patients. However, additional research should be performed on this progression and regarding the ability of patients to return to their specific desired activity.
REFERENCES


**APPENDIX 1: PROPOSED TREATMENT PROGRESSION FOR REHABILITATION AFTER MEDIAL PATELLO FEMORAL LIGAMENT RECONSTRUCTION**

**Weeks 1-4**
Non weight bearing exercises: quad sets, SLR program, modified active knee extension, multangle isometrics (2-4 weeks)

**Weeks 3-6**
Unlock Bledsoe Brace (3-6 weeks)
Adductor strengthening: hook lying ball squeezes, SLR adduction, bridging with ball squeeze.
Advanced strengthening exercises: weight bearing exercises for hip, squats with ball squeezes, lunges, step ups, leg press with ball squeeze, single leg strengthening
Proprioception: static wobble board, dyna disc, BOSU activities

**Weeks 4-10**
Full Weight Bearing Dynamic Proprioceptive: cone touches (6-12 weeks), agility drills, single squat, hopping, walking lunges forward and backward (6-20 weeks)

**Weeks 10-21**
Running: (10-21 weeks): Interval training, alterations in stride length and cadence, progression based on endurance. Plyometrics: box jumps, jump and squat, hop and squat, diagonal hop, over hurdles (13-23 weeks)

**Weeks 14-19**
Sport Specific Drills: cutting, pivoting, activity based on sport (14-19 weeks)

**Weeks 19-36**
Return to sports/functional activity: (19-36 weeks)

**Additional information for Appendix 1**

<table>
<thead>
<tr>
<th>Criteria for Progression</th>
<th>In each stage protect surgical pathology while: progressing ROM, improved quadriceps contraction, decreasing edema, minimizing pain, improving flexibility, and without extensor lag. We observe the improved dynamic functional stabilization of the soft tissue structures, test for adequate strength, without substitution of other muscles. Progression of WBAT to FWB, decreased gait deviations. Key Factors: Endurance: This is the ability to maintain performance, for the entire duration of activity. Power This is the explosive, quick movement necessary to complete an action. An example is the swing of a bat, or golf club.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red flags:</td>
<td>Pain, edema, altered postures to complete an exercise, fatigue on one side compared to another, or substitution from other muscles.</td>
</tr>
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</table>
ABSTRACT

Background and Purpose: Multiple rehabilitation factors including overall wellness need to be considered when an athlete returns to sport after an injury. The purpose of this case report is to describe a multidisciplinary approach for return to sport of a Division I collegiate football player following a traumatic ankle fracture requiring surgical repair. The assessment and treatment approach included the use of a performance-based physical therapy outcome measure, self-reported functional abilities, body composition assessments, and nutritional counseling.

Case Description: A 21 year-old running back fractured his lateral malleolus due to a mechanism of injury of excessive eversion with external rotation of the ankle. Surgical intervention included an open reduction internal fixation (ORIF) of the fibula and syndesmosis. In addition to six months of rehabilitation, the patient received consultations from the team sports nutritionist specialist to provide dietary counseling and body composition testing. The Comprehensive High-level Activity Mobility Predictor-Sport (CHAMP-S), a performance-based outcome measure, self-report on the Foot and Ankle Disability Index (FADI-ADL, FADI-S), and body composition testing using whole body densitometry (BOD POD®), were administered throughout rehabilitation.

Outcomes: The subject was successfully rehabilitated, returned to his starting role, and subsequently was drafted by a National Football League (NFL) franchise. High-level mobility returned to above pre-injury values, achieving 105% of his preseason CHAMP-S score at discharge. Self-reported function on the FADI-ADL and FADI-Sport improved to 100% at discharge. Body fat percentages decreased (13.3% to 11.9%) and fat mass decreased (12.0 kg to 11.0 kg). Lean body mass (78.1 kg to 81.5 kg) and lbm/in increased (1.14 kg/in to 1.19 kg/in). His BMI changed from 29.8 kg/m² to 30.6 kg/m².

Discussion: This case report illustrates the positive effects of a multidisciplinary approach where combining physical therapy and nutritional counseling demonstrated value with return to sport preparation and success following ankle fracture. A targeted physical therapy program combined with a personalized nutrition intervention based on body composition assessment assisted this athlete in avoiding deconditioning (atrophy, decreased aerobic capacities, and increases in body fat) often observed during postoperative care.

Level of Evidence: 5

Key words: ankle fracture, American football, CHAMP-S, FADI, whole body densitometry

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BACKGROUND AND PURPOSE
Football has the highest injury prevalence of all collegiate sports.\textsuperscript{1-3} In-game injuries occur far more frequently than in practice, with rates of 35.9 injuries per 1000 athletic-exposures as compared to 9.6 injuries per 1000 respectively.\textsuperscript{2-3} Furthermore, more than 50% of injuries occurring in football, in either practice or game settings, occur in the lower limb.\textsuperscript{2-3} Player contact is described as the most common mechanism for injuries in football, accounting for 78% of in-game injuries and between 57% (fall) and 69% (spring) of all practice injuries.\textsuperscript{3}

High-level mobility is a required characteristic of sport performance at the elite (collegiate and professional) levels.\textsuperscript{4} Mobility consists of the following physical performance factors: balance, postural stability, coordination, power, speed, and agility. Yet, the use of standardized outcome measures for high-level mobility is not the standard of care in return to sport considerations. For example, when deciding on return to sport in American Football, clinicians must consider the physical prerequisites for safe and successful restoration of function, including the components of high-level mobility.\textsuperscript{4}

The ability to qualify and quantify changes in function are key in rehabilitation. A variety of methods exist to assess baseline function and ultimately to track progress over the course of time. Two of the most commonly used tools for assessing function include physical performance-based measures and patient self-report outcome measures (self-perception). Standardized outcome measures are currently used in the rehabilitation process to determine functional levels, predict mobility, determine the contribution of an intervention, assist with exercise prescription, measure change over time, and document services.\textsuperscript{5} Outcome tools also allow clinicians and patients the ability to monitor and review progress in an objective manner, and may also serve as a means of motivation. Choosing the most appropriate measure is extremely important, taking the medical condition, and short-term and long-term goals into consideration. Additionally, the validity, reliability, testing environment, and ease of use, should all be strongly considered. In general, outcome tools can be classified as assessing impairments, body function (physiologic and/or neuromuscular function), activity (execution of a task of function), participation (involvement with life situation), and environmental factors (physical, social, attitudinal).

Prognostic indicators related to body composition and injury risk have been identified in the literature.\textsuperscript{6-8} High body fat percentage (%fat) and higher body mass index (BMI) have both been associated with an increased risk of injury in competitive athletes. More specifically, body fat % and BMI have been highly correlated to an elevated risk of lower limb injury.\textsuperscript{7-8}

A relationship between athletic performance enhancement and nutritional intake and body composition has been reported.\textsuperscript{9} The dietary habits of consuming proportionally higher intakes of processed and refined foods, saturated fats, and lower intakes of fresh fruits and vegetables, are prevalent across the general populous, including athletes. Such diets contribute to overall poor health and can impair athletic performance.\textsuperscript{9} Ideal body composition varies by athlete but in general, the less fat mass, the greater the performance potential.\textsuperscript{9} Measurements of body composition are valuable tools when determining appropriate nutritional intake, since there is a direct relationship between dietary intake and body composition.\textsuperscript{9} Excessive levels of body fat (%) can indicate poorer levels of conditioning and athletic performance or unbalanced dietary consumption.\textsuperscript{9}

The purpose of this case report is to describe a multidisciplinary approach for return to sport of a Division I collegiate football player following a traumatic ankle fracture requiring surgical repair. The objective measures tracked in this case included high-level mobility, self-reported function, and body composition.

CASE DESCRIPTION: PATIENT HISTORY AND SYSTEMS REVIEW
A 21-year-old male Division I collegiate football player sustained a distal fibula fracture, subluxation of the talus, and a tear to the deltoid ligament while running with the ball late in a game. While being tackled in a crouched position, his upper body rolled posteriorly over a planted and externally rotated right foot, causing a traumatic eversion and external
rotation force to the ankle, resulting in a fracture to the distal fibula. He was immediately removed from the game and the ankle was placed in a short leg immobilization boot. He had no prior significant medical history.

Radiographs confirmed an oblique and slightly displaced fracture to the distal fibula (Figure 1). The orthopaedic surgeon decided that an open reduction with internal fixation was necessary and surgery was performed two days following the injury. An 8-cm lateral incision was made over the fibular fracture site and the superficial fibular nerve was identified and protected. Three lag screws were placed through the fracture site, with 3.5 cortical screws to lag the fracture site. An Arthrex neutralization plate was put into place to provide additional stability. Three more cortical screws were placed proximally and two screws were placed distally to the fracture site. The syndesmosis between the tibia and fibula was widened, thus two Arthrex Tight Rope fixations were inserted to stabilize the syndesmosis (Figure 2). The subject was placed in an ankle orthosis following surgery. There were no surgical complications.

At the time of his initial physical therapy evaluation, the subject was informed that the data concerning his case would be submitted for publication. The subject’s confidentiality was protected according to the U.S. Health Insurance Portability and Accountability Act (HIPPA) and IRB approval for this case report was granted. The subject participated in a sport-specific physical therapy program in the athletic training facility after discharge from the hospital.

The subject's postoperative presentation was unremarkable for complications and he was able to participate in daily rehabilitation sessions under the supervision of the physical therapist and athletic trainer. The subject progressed through the treatment protocol within surgical precautions accounting for his stated goals of returning to sport, and at the same time adding lean body mass prior to the commencement of the upcoming season. The subject was examined and monitored over the course of his rehabilitation by a multidisciplinary team, which included an orthopaedic surgeon, physical therapist, athletic trainers, and an exercise physiologist who serves as a sports nutrition specialist for all university varsity teams.

**CLINICAL IMPRESSION #1**

When considering an appropriate physical performance-based measure for return to sport it is essential to analyze the participant’s position-related needs. The position of running back necessitates multidirectional movements that stress the body's ability to accelerate, decelerate, pivot, and transition with remarkable force and speed. Running backs are also involved with plays that vary in distance, and thus need to have appropriate aerobic and anaerobic capacities.

Considerations for successful rehabilitation of distal fibular fractures includes careful progressions through weight-bearing activities, gradually...
increasing physiologic responses to exercise, and limiting pain-inducing or exacerbating activities (Table 1). Therefore, successful rehabilitation was defined for this subject by the following measures: 1) attaining functional range of motion, joint mobility, and strength 2) achieving pre-injury baseline scores on the Comprehensive High-Level Activity Mobility Predictor-Sport (CHAMP-S), and 3) self-reported full functional abilities on the FADI-ADL and FADI-Sport. The intervals for completing the functional outcome measure and self-report were based on periods of transitions between phases of rehabilitation.

EXAMINATION
The Comprehensive High-Level Activity Mobility Predictor (CHAMP) is a reliable, valid, and responsive performance-based outcome measure of high-level mobility that was developed in order to assess readiness to return to high-level activity and return to duty for service members and veterans with traumatic lower limb loss.10-11 The four tests that make up the CHAMP are: Single Limb Stance (SLS), Edgren Side Step Test (ESST), T-Test, and the Illinois Agility Test (IAT). The CHAMP has been adapted to the CHAMP-S, specifically for the athletic population, by modifications made to two of the CHAMP items.12 Modifications were made to the ESST and T-Test. The CHAMP-S contains 26 items and the CHAMP-S contains eight items, with each scored from 0 (unable to do) to 4 (no difficulty at all). The 4 pain items of the CHAMP-S are scored 0 (none) to 4 (unbearable). The CHAMP-S has a total point value of 104 points, whereas the FADI-S has a total point value of 32. The CHAMP-S and FADI-S are scored separately as percentages, with 100% representing no self-reported dysfunction.14 Both the CHAMP-S and FADI-S have been found to be the most appropriate evaluative instruments to quantify functional disabilities in athletes with chronic ankle instability (CAI).13-20 The CHAMP-S and FADI-S have been found to be reliable and valid in assessing progress during rehabilitation in patients with CAI when used at one-week and six-week intervals between administration.13-20

The current gold standard for measuring body composition is hydrostatic weighing.9,21-22 However, this method is time consuming and requires a great amount of technical expertise. As of the mid 1990's another technique known as air-displacement plethysmography (ADP) has been widely accepted as valid, reliable and much easier to implement.9,21-22 A commercial device known as the BOD POD® (Life Measurement Instruments, Concord, CA) utilizes ADP, which is more accurate than BMI in estimating body composition in male athletes, as BMI typically grossly overestimates body fat in athletes.23

The BOD POD® is used to estimate the fat and fat-free mass percentages. The BOD POD® uses ADP to assess body volume and estimate %fat.24 ADP estimates body density by deriving body volume and measuring body mass. The Bod Pod® then calculates %fat from body density estimates using equations proposed by Siri and Brozek and colleagues.24 The results can then be used to calculate body density using the mass/volume ratio.25 The BOD POD® is a reliable and valid tool when assessing %fat in both male and female participants.9,24-27 Although there is strong test-retest reliability for %fat assessment using the BOD POD®, %fat scores have been found to be slightly lower than values for hydrostatic weighing (HW), dual-energy X-ray absorptiometry (DXA),
<table>
<thead>
<tr>
<th>Goals</th>
<th>Precautions/Contraindications</th>
<th>Suggested Exercises</th>
<th>Physical Performance Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase I</strong></td>
<td>- Protect fixation</td>
<td>- Aerobic Conditioning</td>
<td>- FADI-ADL</td>
</tr>
<tr>
<td></td>
<td>- Initiate early motion</td>
<td>- Upper body ergometer</td>
<td>- FADI-Sport</td>
</tr>
<tr>
<td></td>
<td>- Prevent stiffness and loss of bone density</td>
<td>- Cryotherapy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Promote cartilage health, decrease pain, edema, inflammation</td>
<td>- Edema and pain control through electrical stimulation (TENS, microcurrent, high-volt)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Decrease muscle atrophy</td>
<td>- ROM</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Educate patient and family if needed</td>
<td>- Ankle PROM → AAROM → AROM</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>- Static stretching</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>- Ankle pumps</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>- Towel stretches</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>- Ankle alphabet</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Strength</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Manual resistance at thigh and hip in all planes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Intrinsic toe flexion</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Ankle isometrics in all planes</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>- Proximal Hip PNF D1/D2</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td><strong>Balance</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Weight shifting in all planes</td>
<td></td>
</tr>
<tr>
<td><strong>Phase II</strong></td>
<td>- Restore talocrural and subtalar ROM (~80%) and &gt;4/5 strength</td>
<td>- WBAT to FWB dependent on pain and ROM, as well as fixation and callous formation</td>
<td>- FADI-ADL</td>
</tr>
<tr>
<td></td>
<td>- Maintain or improve strength of lower extremity and core musculature</td>
<td>- Peroneal tendinitis due to hardware</td>
<td>- FADI-Sport</td>
</tr>
<tr>
<td></td>
<td>- Control edema</td>
<td>- Nonunion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Maintain optimal bone and soft tissue healing environment</td>
<td>- Hardware failure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Increase proprioception, balance, coordination</td>
<td>- Compartment syndrome</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Single-limb balance (≥30 seconds)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td><strong>Aerobic Conditioning</strong></td>
<td>- CHAMP-S</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Stationary bike → Elliptical → Stairclimber</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Modalities</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- As needed</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>ROM</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Ankle PNF stretching in all planes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Foam rolling program</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Scar mobilizations</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Strength</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Open chain isotonics for the lower limb</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Manual resistance to the ankle, knee, hip</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Lower limb PNF strengthening D1/D2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Seated and standing isotonic calf raises</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>- Squats progression</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Lunge progression</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Core stabilization</td>
<td></td>
</tr>
</tbody>
</table>
| Phase III | Return to football-specific training  
- Self-report on FADI-ADL and FADI-Sport at 100%  
- Achieve 90% of baseline CHAMP-S score | Abnormal pain, swelling, edema, lack of posterior tibial artery pulse  
- Hardware failure  
- Posttraumatic arthritis  
- Compartment syndrome  
- Peroneal tendinitis | Aerobic Conditioning  
- Alter G treadmill  
- Hydroxor treadmill  
- Jog → Run Progression  
ROM  
- Self-stretching  
Strength  
- Continued squat progression  
- Continued lunge progression  
- Plyometric progression  
- Proprioception, Coordination, Balance  
- Addressing movement impairments as noted through CHAMP-S testing  
- Programmed → Reactive coordination drills  
- Agility training (ladders, dot drill, cutting, shuttle) | - FADI-ADL  
- FADI-Sport  
- CHAMP-S |
|---|---|---|---|---|
| Phase IV | Return to premorbid participation avoiding the “overdo” complex; full return to sport | Abnormal pain, swelling, edema, lack of posterior tibial artery pulse  
- Hardware failure  
- Posttraumatic arthritis  
- Compartment syndrome | Aerobic Conditioning  
- Football-related  
ROM  
- Maintenance of dorsiflexion mobility  
Strength  
- Return to team lifting  
Proprioception, Coordination, Balance  
- Maintenance of single limb stance balance | As needed |

DVT= Deep vein thrombosis, TENS= Transcutaneous electrical nerve stimulation, AROM= Active range of motion, AAROM= Active-assistive range of motion, PROM= Passive range of motion, WBAT= weight bearing as tolerated, FWB= full weight bearing, FADI-ADL= Foot and Ankle Disability Index-Activities of Daily Living, FADI-S= Foot and Ankle Disability Index-Sport, CHAMP-S= Comprehensive High-level Activity Mobility Predictors-Sport, PNF= Proprioceptive neuromuscular facilitation
and three compartment modeling (3C). The technical error of measurement for the BOD POD® was lower, with a value of 0.40%, than those reported for HW (0.42%) and skinfold measures (0.61%).

**CLINICAL IMPRESSION #2**

Due to the nature of the subject’s initial non-weight bearing status and its potential impact on disuse atrophy and overall decreased abilities for aerobic conditioning, the treating physical therapist believed nutritional counseling would have a positive impact in the early phases of his recovery. In addition, the subject’s stated goal of gaining lean body mass and increasing his total body weight needed to be initially measured and monitored during his post-operative care. The subject had a history of poor eating habits, which he expressed to the nutritional counselor at the time of his first consult. Therefore, the team sports nutrition specialist was included to both counsel the subject on his diet and also track changes in body composition using the BOD POD®.

**INTERVENTION**

A four-phased rehabilitation program began one day after surgery. The phases were divided into: protection (I), functional progression (II), sport-specific (III), and supervised sport activities (IV).

**Protection (Phase I):** The protection phase began with a non-weight bearing protocol to allow for proper fixation and soft-tissue healing. After one month, the subject was transitioned to toe-touch weight bearing after radiographs showed soft callous healing. Rehabilitative goals at this time were to protect the post-operative ankle, eliminate effusion, restore adequate range of motion, and mitigate weakness caused by arthrogenic muscle inhibition. These goals were achieved by controlling ankle joint swelling and pain, regaining appropriate voluntary contraction of the leg musculature, initiating immediate knee and hip motion, and educating the subject on minimizing the time spent with the ankle in a dependent position by adequately elevating his limb.

**Functional Progression (Phase II):** The rehabilitation goals for the functional progression phase were to achieve full active ankle range of motion, gain trunk and lower extremity strength (>4/5 MMT), initiate generalized aerobic conditioning, normalized gait, single-limb balance (≥30 seconds) with postural steadiness, and uncompensated pain-free mobility. During this phase, careful progressions were initiated to begin stressing the ligamentous complexes about the ankle. This was done by advancing closed kinetic chain exercises while ankle pre-positioning the ankle from a neutral to inversion and ultimately eversion posture. CHAMP-S testing was initiated during this phase to allow the physical therapist and athletic trainers to develop an exercise-based intervention targeting any balance and/or mobility deficiencies noted.

**Sport-Specific Phase (Phase III):** At four months post-op, the subject was cleared to begin participating in position-specific agility drills and weight room workouts with the team. Goals for the subject during this phase included a return to football-specific training, self-report scores on FADI-ADL and FADI-Sport of 100%, and to achieve 90% of his pre-season CHAMP-S score.

The plan of care began shifting to football-specific activities, with interventions focusing on normalizing limb function and lower-quarter strength, movements incorporating skill, lower extremity stability, and agility drills. Higher-level impact training was initiated in the pool, and ultimately transitioned to dynamic surfaces.

**Supervised Sport Activities (Phase IV):** The goals for the subject during this phase were a return to pre-morbid participation levels. During this phase, the subject was able to perform independent stretching and strengthening exercises, participate in a structured aerobic and sport-specific condition, and partake in self-relaxation activities. Full return to sport was gradually incorporated in returning to supervised sport-specific activities with his coaches. At the six-month mark, he was cleared for all activities.

The CHAMP-S was used to assess high-level mobility over the course of his rehabilitation and assist with determining readiness to return to sport. The CHAMP-S provides insight into rehabilitation factors: 1) early success in single-limb stance cleared the subject for progressions in therapy; 2) assistance with identifying limitations in movement in different planes of motion that are of immediate concern to better customize plan of care; and 3) integrates the
subject into the rehabilitation process by providing him or her with immediate performance feedback which could improve confidence and motivation in sport-specific agility movements. Asymmetries in movement and slower test interval times relative to his pre-season scores were evaluated for causative factors, including strength and flexibility testing of the muscle groups involved with movement in that plane, neuromuscular control (balance, coordination, and power), muscle activation, and postural factors.

The goal for the subject of this study was to achieve ± 5% from his original preseason, preoperative, baseline composite CHAMP-S scores. The CHAMP-S was initiated once the subject was allowed to ambulate without an assistive device and was administered at least once per phase of rehabilitation, with progressions from brisk walking in the earlier phases to ultimately maximal exertion. It was hypothesized that the subject would improve his overall score as he progressed through rehabilitation.

The BOD POD® was used to estimate the fat and fat-free mass percentages at two distinct points in his rehabilitation. All testing was performed in accordance with the manufacturer’s instructions. Testing on the Bod Pod® is convenient and minimally burdensome. The testing protocol requires sitting in the Bod Pod®, breathing through a tube, and providing three short bursts of exhalations. The subject was to undergo his consult with the team nutritionist shortly after surgery. The plan was for the sports nutrition specialist to counsel the subject on both caloric intake guidelines and on dietary recommendations. Lower caloric intake recommendations were important to coincide with lower caloric expenditure, especially during the earlier phases of rehabilitation. As the subject began to progress with higher activity demands during the later phases of rehabilitation, higher caloric intake levels were recommended. The goal was for body composition measurement to match his dietary consumption, assuming he remained compliant with his nutritional plan.

Caloric intake prescription for the subject was calculated using his goal-weight for the upcoming season and current levels of energy expenditures. Caloric recommendations were then made to address improving lean body mass (LBM) over the course of his recovery. LBM is defined as the weight of fat-free mass (bone, water, muscle, vasculature, connective tissue) and is measured in either pounds or kilograms. LBM is the primary contributor to resting energy expenditure as well as overall caloric expenditure, therefore, this method of calculating caloric intake needs is individualized for body composition goals.30 Given the physiological requirements of football, the nutritionist recommended a nutrition plan with energy requirements based on LBM consisting of 60% carbohydrate, 20% protein and 20% fat.30 This macronutrient ratio is within the standards of optimum performance for football.30 Previous research has shown that dietary modifications have a positive effect on body composition.31

Prior to injury, the subject’s caloric needs were estimated at 4340 kcal/day. Postoperatively, it was recommended that he reduced his caloric intake to 3514 kcal/day to accommodate the significant reduction in energy expenditure during the early phases of rehabilitation. The macronutrient recommendation stayed relatively unchanged; however, the subject was counseled to reduce intake of simple sugars, specifically beverages, and processed carbohydrates, while increasing his intake of fruits and vegetables. As the subject progressed through rehabilitation, and as both exercise intensity and energy expenditures increased, adjustments to the caloric intake recommendations were made accordingly. Once he was cleared to begin full football activities, he was re-assessed with the BOD POD® and a recommendation to increase his caloric intake to 4416 kcal/day was made.

OUTCOME

As part of standard of care, range of motion (ROM) measurements and manual muscle testing (MMT) were administered throughout the rehabilitation process. ROM and MMT were symmetric bilaterally at the time of discharge from rehabilitative care. A timeline summary of relevant events can be found in Table 2.

At eight months postoperative, the subject was able to improve on his preseason performance by demonstrating an increase in his CHAMP-S score of 5% when compared to baseline score (60 to 63). He was able to maintain SLS for 30 seconds two months
postoperatively and maintained this performance at all testing sessions. The mESST improved 74.2% from a score of 8 at two months to a score of 15 at eight months. The subject also improved in the L-Test by 71.7%, from a score of 5 at two months to a score of 13 at eight months. An interesting finding provided by the CHAMP-S was that the subject consistently exhibited faster times with left lateral agility (i.e., side-stepping towards the left with his right surgically repaired limb acting as the trailing/propelling limb) as compared to right lateral agility at baseline and throughout the rehabilitation process. The subject improved in the IAT by 70.7%, from a score of 6 at two months to a score of 15 at eight months (Table 3).

The subject scored 100% on the FADI-ADL and FADI-S at five months after surgery, suggesting the subject perceived he had fully recovered. The FADI-S is unique in that it is a population-specific subscale designed for athletes. Many subjective reports of function are designed to be used among older populations or populations with limitations in the performance of activities of daily living. When such scales are used in athletic populations, a ceiling effect may be observed: athletes score at the extreme high end of normal function. This, in turn, decreases the sensitivity of the scale to functional deficits and treatment effects. Therefore, the subject's scoring at the highest level is of clinical significance.

Changes in %fat and LBM, as measured by the BOD POD®, were found over the two testing periods. There was a decrease in %fat from 13.3% to 11.9% (-1.4%) and LBM increased from an immediate post-injury value of 78.1 kg to 81.5 kg (+ 3.4 kg) at six months. During rehabilitation, his total mass increased from 90.1 kg to 92.5 kg (+2.4 kg). The subject also gained 4.99 kg of total body weight prior to the start of the following season (Table 4).

**DISCUSSION**

Elite football players are susceptible to ankle injuries due to high rotational and large impact forces placed on the ankle during running, cutting, and tackling. It has been reported that 72% of players that presented to the 2006 NFL Combine had a
history of foot and ankle injury. It has been speculated that the skill-position players (running backs and wide receivers) have an increased risk of lower extremity injury because of the amount of rotational forces associated with cutting and agility maneuvers. Several authors have supported this assertion, stating that the running back position in particular is at an increased injury risk. Data gathered at the 2006 NFL combine found that running backs had the highest percentage of foot and ankle surgeries upon presentation compared to all other positions.

Surgical reduction and rigid internal fixation at the fracture site reduces the probability of a future dis-

Table 3. **CHAMP-S scores: Baseline and post-operative**

<table>
<thead>
<tr>
<th></th>
<th>Date Baseline</th>
<th>Date 2 Months</th>
<th>Date 4 Months</th>
<th>Date 8 Months</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLS</td>
<td>Best Time(s)</td>
<td>Score</td>
<td>Best Time(s)</td>
<td>Score</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Right</td>
<td>30</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>mESST</td>
<td>8.38</td>
<td>14</td>
<td>10.85</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I-Test</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forward</td>
<td>2.47</td>
<td>3.46</td>
<td>2.53</td>
<td>2.41</td>
</tr>
<tr>
<td>Right SS</td>
<td>2.40</td>
<td>3.45</td>
<td>2.79</td>
<td>2.56</td>
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<tr>
<td>Left SS</td>
<td>2.86</td>
<td>4.08</td>
<td>3.04</td>
<td>2.81</td>
</tr>
<tr>
<td>Backward</td>
<td>2.98</td>
<td>3.88</td>
<td>2.98</td>
<td>2.88</td>
</tr>
<tr>
<td>Total Time</td>
<td>10.71</td>
<td>12</td>
<td>14.87</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IAT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T + COD</td>
<td>5.88</td>
<td>7.63</td>
<td>6.11</td>
<td>5.05</td>
</tr>
<tr>
<td>Weave</td>
<td>5.52</td>
<td>7.26</td>
<td>6.32</td>
<td>5.31</td>
</tr>
<tr>
<td>COD</td>
<td>4.99</td>
<td>6.81</td>
<td>5.03</td>
<td>4.99</td>
</tr>
<tr>
<td>Total Time</td>
<td>16.39</td>
<td>14</td>
<td>21.70</td>
<td>17.46</td>
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<td></td>
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<tr>
<td>Total CHAMP-S Score</td>
<td>60</td>
<td>39 (65%)*</td>
<td>53 (88%)*</td>
<td>63 (105%)*</td>
</tr>
</tbody>
</table>

Comments:
Abbreviations: SLS= Single Limb Stance; mESST= Modified Edgren Side Step Test; IAT= Illinois Agility Test; SS= Side Step; T+COD= Transfer to Standing + Change of Direction; COD= Change of Direction

CHAMP-S item scores = 0 – 20; Total CHAMP-S score range: 0-80

*Percentage of baseline

Table 4. **Body composition changes**

<table>
<thead>
<tr>
<th>Post-Operative Week</th>
<th>Weight (kg)</th>
<th>Body Fat %</th>
<th>Lean Body Mass (LBM) (kg)</th>
<th>Fat Body Mass (kg)</th>
<th>Height (in)</th>
<th>LBM/In (kg/in)</th>
<th>BMI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preseason</td>
<td>87.7</td>
<td>6.5</td>
<td>82.1</td>
<td>5.71</td>
<td>68.5</td>
<td>1.20</td>
<td>29.1</td>
</tr>
<tr>
<td>8</td>
<td>90.1</td>
<td>13.3</td>
<td>78.1</td>
<td>11.9</td>
<td>68.5</td>
<td>1.14</td>
<td>29.8</td>
</tr>
<tr>
<td>20</td>
<td>92.5</td>
<td>11.9</td>
<td>81.5</td>
<td>11.0</td>
<td>68.5</td>
<td>1.19</td>
<td>30.6</td>
</tr>
</tbody>
</table>
placement.\textsuperscript{37} Furthermore, internal fixation provides the joint with an increased ability to withstand early weight bearing and ankle motion, thus allowing rehabilitation only a few days following surgery.\textsuperscript{37} Authors have also found quicker improvements in return to ADLs and work, in subjects that underwent early functional exercise and weight-bearing following internal fixation of the ankle.\textsuperscript{37,38}

The CHAMP-S was successfully used as a performance-based outcome measure of high-level mobility to determine the subject’s current function, change in function throughout the rehabilitation process and to determine readiness to return back to sport safely. The goal of returning the subject to +/- 5% was the result of a pilot study conducted that looked to establish the CHAMP-S as a measure of return to sport following lower limb injury in Division I collegiate student-athletes. The results of the study found that the 10 student-athletes who returned to sport safely following a lower limb injury, and did not sustain a re-injury to the ipsilateral or contralateral limb, achieved a mean return to sport CHAMP-S score of 103% +/- 5% with a range from (95 - 109%). A major benefit of the CHAMP-S test is that it allowed the rehabilitation team to assess mobility once the subject was able to ambulate with his full body weight. Other commonly used functional tests (i.e. hop test, jump test, etc.) cannot be performed in the earlier rehabilitative phases due to the higher levels of impact on the involved limb. In addition, as the subject progressed in exercise intensity and began to perform bi-planar, and multi-planar movements, the rehabilitation team was able to identify limitations in mobility, allowing for targeted prescriptive exercises to address his limitations.

Generally, measurements of strength, ROM, and functional tests are the standard criteria for assessment of an athlete’s progression through rehabilitation.\textsuperscript{39-41} More specifically the Limb Symmetry Index (LSI) is frequently used as a measure of function, comparing either distance or time of the involved to the uninvolved limb when performing a single-limb task (single leg hop testing). However, as with many other return to sport assessments, there are noted limitations with the LSI. The primary issue is the utilization of the uninvolved limb as a standard of optimal function. The LSI uses relative, comparative data that neglects the influence of past injury or other limitations that currently affect the uninvolved limb in both strength and function. Though having pre-injury data to compare with post-injury results could serve to minimize such limitations,\textsuperscript{39,42-44} Isokinetic testing that is used to determine strength of the involved limb using LSI can also fail to account for these limitations of uninvolved leg and, like hop testing, is prohibited in early phases of rehabilitation following many lower extremity injuries.\textsuperscript{38,45} Additionally, other studies have shown poor correlation of LSI scores with self-reported knee function as well as inconsistent results under fatigued conditions.

Verstegen et al\textsuperscript{46} also emphasized that sports involve multidirectional movements, stressing the body’s ability to decelerate, pivot, and transition with remarkable force and speed. Thus, there is a need for an outcome measure to assess all these movement variables in multiple planes of motion throughout the continuum of rehabilitation, starting in the early postoperative phases and continuing through to return to sport activities. This type of outcome measure can help objectify return to play considerations, while increasing player confidence that the risk of re-injury may be minimized.\textsuperscript{39,41,46-47}

Self-reported function was tracked using the FADI-ADL and FADI-S scales. The FADI-S has been shown to be reliable in detecting functional limitations in subjects with chronic ankle instability and is sensitive to differences between healthy subjects and subjects with CAI.\textsuperscript{13} The FADI-ADL and FADI-S are also sensitive to improvements in function after rehabilitation in subjects with CAI. Since CAI is a condition that specifically hinders rigorous and athletic activity without affecting low-level task, the FADI-ADL and FADI-S were deemed an appropriate self-report outcome instrument for this case.\textsuperscript{16}

The subject in this case report attained full scores on both the physical performance-based and self-report measurements. It should be noted that several authors have compared the level of agreement between performance-based measures and self-report.\textsuperscript{48-50} Shulman et al\textsuperscript{48} found low to moderate agreement between measures, with a moderate correlation (r = .48) between patient’s self-reported difficulty in performing tasks and observer assessment. After
the patients actually performed the tasks, the correlation increased (r = .78). The authors concluded a mismatch may exist between how patients believe they function and how they actually function.48 Similar results were found in patients undergoing total knee arthroplasty, where important limitations in knee function and performance deficits were unrecognized by self-report outcome measures.49-50 Therefore, clinicians and researchers should consider supplementing self-report with performance-based measures.

Body composition is an important factor to consider throughout the rehabilitation process. Higher BMI, as a result of higher relative body weights, has been shown to increase the risk of injury in male military recruits, due to the higher compressive forces during activities such as running, walking and marching, specifically in overuse injuries.51 However categorizing athletes using BMI may disproportionately misclassify them as overweight or obese due to their more muscular physiques and higher bone mineral density values when compared to sedentary individuals. Therefore, the use of body composition measures, such as LBM, in an athletic population could present an opportunity for future studies. In a study of Gaelic football players, Watson demonstrated that a higher preseason LBM value correlated with a lower risk of injury during the season.52 Alternatively, those players who had a reduction in LBM from preseason to mid-season, suffered an increase in the rate of injuries.52 In this case report, the subject had an increase in LBM, total body weight, and BMI, and a decrease in %fat. Of note, the subject did play the entire following season without missing any playing time due to injury.

Despite the wide spread practice of using %fat and BMI tracking in both determining and monitoring goal-weights in amateur and professional athletes, there are no published studies that incorporate these measures in tracking body composition changes throughout the course of rehabilitation. It is considered general knowledge that athletes undergo degrees of deconditioning following injury, immobilization, and surgery, specifically as it relates to increases in fat. However, it is not common physical therapy practice to refer to other allied health professionals to measure body composition during rehabilitation.

CONCLUSION

The results of this case report demonstrate that it is possible to safely return to sports following a surgically repaired traumatic ankle fracture while, concurrently, improving high-level mobility, self-reported function, and body composition. The subject was successfully rehabilitated, returned to his starting role, and was subsequently drafted by a National Football League franchise. Sport-specific rehabilitation, body composition testing, and nutritional education with dietary counseling were key components in this process. Adjusting nutritional consumption and monitoring body composition in order to increase lean muscle mass and total mass while decreasing fat mass is possible while concurrently improving high-level mobility, as measured by the CHAMP-S. Clinicians should consider a similar multidisciplinary approach to enhance outcomes and performance for their injured athletes.

REFERENCES


ABSTRACT

Background and Purpose: Patellofemoral pain syndrome (PFPS) is a common source of anterior knee pain. Controversy exists over the exact clinical findings which define PFPS, thus, diagnosis and management can be challenging for clinicians. There is paucity in the literature concerning joint mobilization as treatment for PFPS, particularly at the tibiofemoral joint, as standard management is currently focused on therapeutic exercise, orthotics, bracing and taping. Therefore, the purpose of this case report is to describe the effects of tibiofemoral joint mobilization in the successful treatment of an individual with chronic PFPS as it relates to pain, function and central processing of pain.

Study Design: Case Report

Case Description: The subject was a 28-year-old female with a two year history of left anterior, inferior patellar knee pain consistent with chronic PFPS. She demonstrated diminished pressure pain threshold (PPT) and allodynia at the anterior knee, suggesting a component of central sensitization to her pain. She met several common diagnostic criteria for PFPS, however, only tibiofemoral anterior-posterior joint mobilization increased her pain. Subsequent treatment sessions (Visits 1-6) consisted of solely joint mobilization supplemented by instruction in a home exercise program (therapeutic exercise and balance training). As outcomes improved, treatment sessions (Visits 7-8) consisted of solely therapeutic exercise and balance training with focus on return to independent pain free functional activity.

Outcomes: Improvements consistent with the minimally clinically important difference were noted on the Kujala Anterior Knee Pain Scale, Numeric Pain Rating Scale, Global Rating of Change (GROC). Scores on the Fear Avoidance-Belief Questionnaire (6/24 to 2/24 PA, 31/42 to 5/42 W), PPT (119 to 386 kPa) and Step Down Test (11 to 40 steps) also demonstrated improvement. At a two month follow up, the subject reported continued improvement in functional activity, 0/10 pain and GROC = +5.

Discussion: This case describes the successful use of tibiofemoral joint mobilization in a subject with chronic PFPS and supports the use of joint mobilization as management in PFPS, particularly in cases where a centrally mediated component of pain may be present.

Level of Evidence: Therapy, Level 5

Keywords: Central sensitization, manual therapy, patellofemoral pain syndrome, pressure pain threshold
BACKGROUND AND PURPOSE
Patellofemoral pain syndrome (PFPS) is a common source of anterior knee pain which accounts for 25-40 percent of all knee problems seen in sports medicine centers once other potential sources of pain are excluded.1,2 Direct and indirect medical costs of PFPS were approximately $1500 per subject during 2010 in Scandinavian countries and can be assumed to be even higher in North America.3,4 PFPS is commonly described as sharp or dull pain in the anterior or retropatellar knee that can be aggravated by sustained sitting (“theater sign”), kneeling, stair ambulation, and squatting.5 Due to notable design and reporting bias in the studies evaluating the diagnostic accuracy of clinical tests for PFPS, no single test has been identified as particularly useful in the diagnosis of PFPS.6,7 Clinical diagnosis of PFPS is primarily one of exclusion due to the high variability of risk factors that can produce similar pain and symptoms at the knee (Table 1). While the etiology is unknown and controversy exists over the exact clinical findings which define PFPS,2,8 it is not surprising that diagnosis and management can be challenging for clinicians.8 PFPS often becomes a chronic condition that may fail to respond to conservative measures9 and is more common in the female population9,10.

Therapeutic exercise11-16 bracing17,18 taping19,20 and orthotics21,22 have all shown some level of benefit in the treatment of PFPS; however, there is paucity in the literature regarding the effects of joint mobilization in the treatment of chronic PFPS. As a result, joint mobilization may be less considered in routine physical therapy care in those with chronic PFPS as there is little evidence to support its effectiveness in managing pain and function in this population. Patellar mobilization alone demonstrated no significant improvement in pain23,24 while manual therapy combined with multimodal treatment or exercise resulted in only fair treatment outcomes in the short term and long term for PFPS.25 Lumbar manipulation has been shown to be beneficial in a small population of subjects with PFPS for pain reduction, however, more research is needed to explore the efficacy of this treatment approach.26 There is also conflicting evidence as to whether lumbar manipulation is beneficial in increasing knee extensor strength and force output.27,28

PFPS is assumed to be multifactorial in nature; it is necessary to thoroughly examine and broadly hypothesize potential contributing factors and structures for successful management. To the authors’ knowledge, only one study has ever researched the effects of joint mobilization directed at the tibiofemoral joint in this subject population; the study’s main focus being normalization of biomechanics and movement patterns.30 Therefore, the purpose of this case report is to describe the effects of tibiofemoral joint mobilization in the successful treatment of an individual with chronic PFPS as it relates to pain, function and central processing of pain.

CASE DESCRIPTION
Subject History and Systems Review
The subject was a 28-year-old female with two year history of left anterior knee pain, significant functional limitations, without significant findings on magnetic resonance imaging (MRI). Intermittent

<table>
<thead>
<tr>
<th>Table 1: Differential Diagnoses for Anterior Knee Pain</th>
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<tbody>
<tr>
<td>Articular Cartilage Injuries</td>
</tr>
<tr>
<td>Pes anserine Bursitis</td>
</tr>
<tr>
<td>Hoffa’s Disease</td>
</tr>
<tr>
<td>Patellar Instability</td>
</tr>
<tr>
<td>Osteoarthritis</td>
</tr>
<tr>
<td>Plical Synovitis</td>
</tr>
<tr>
<td>Quadriceps Tendinopathy</td>
</tr>
<tr>
<td>Sindig Larsen-Johansson Disease</td>
</tr>
<tr>
<td>Bone Tumors</td>
</tr>
<tr>
<td>Iliotibial Band Syndrome</td>
</tr>
<tr>
<td>VMO Trigger points</td>
</tr>
<tr>
<td>Patellofemoral Arthritis</td>
</tr>
<tr>
<td>Slipped Capital Femoral Epiphysis</td>
</tr>
</tbody>
</table>
pain began after a fall on her anterior knee two years prior while moving boxes at work, only to be reaggravated by another fall, 20 months later, onto the same location of the knee. After the initial injury, the subject underwent physical therapy consisting of therapeutic exercise, pain education, and a graded motor imagery program. She ultimately failed to show progress and stopped attending physical therapy secondary to external family issues. After the second trauma, her intermittent knee pain progressively worsened and the subject sought medical assistance from her sports medicine physician. She was referred her to outpatient physical therapy for the second time with a diagnosis of PFPS.

At the time of her initial evaluation, the subject presented with an antalgic gait and was wearing a soft neoprene brace on the left knee. The subject's main complaints included diffuse left anterior, inferior patellar-region pain (Figure 1.) during activities of squatting, stair ambulation, prolonged walking and kneeling. Her symptoms were described as sharp with initial activity and a dull ache after prolonged activity which could be further accentuated by cold weather. At times, she felt pain radiating to the posterior knee and anterior lower leg with prolonged exposure to the aforementioned aggravating activities. She reported left leg instability and weakness which she also attributed to pain. Symptoms had progressively worsened until she was ultimately laid-off from work because she was unable to accomplish her job duties of heavy lifting. Her pain was alleviated by medication and frequent sitting breaks. She denied any history of back pain, cancer, cardiovascular involvement, paresthesias, or contralateral lower extremity (LE) symptoms. She had no previous occurrences of anterior knee pain and was very active in sports as a teenager.

Past medical history was significant for the subject being overweight (height 158 cm, weight 66.8 kg, BMI = 26.76 kg/m²), an unspecified left LE surgery for “club foot” at three months of age and pelvic inflammatory disease secondary to infected pelvic intrauterine device which was removed one year prior to the initial physical therapy evaluation. The subject was no longer employed, was a single parent and part-time student. The subject’s primary goal was to be able to resume her previous functional activities, which included exercising, dancing, and prolonged walking with less pain.

Clinical Impression I

Based upon the results of the subjective examination, signs and symptoms were most consistent with a clinical working diagnosis of chronic PFPS; however, there was concern about some aspects of her clinical presentation. While the subject met common subjective diagnostic criteria for PFPS such as anterior knee pain during squatting, stair ambulation, prolonged walking and kneeling, intra-articular tibiofemoral pathology or lumbar/hip referral of symptoms were also considered. It was also hypothesized that the persistent nature of her condition may have resulted in central sensitization of nociceptive mechanisms. With a significant noxious event, repetitive noxious stimuli, and/or the influence of biopsychosocial factors, central processing changes can be demonstrated months past the expected healing time of the injury and resolution of the inflammatory state. These central changes can potentially lead to chronic pain, sensory disturbances and further functional impairments. Subjective findings supporting the possible presence of central sensitization were her complaints of knee instability, chronicity of symptoms, previous failed conservative management, cold thermal hypersen-
sitivity, and her report of several external emotional stressors (recent lay-off and current unemployment, single parent).31-34 Due to the above subjective findings, it was necessary to not only provide a thorough physical examination locally at the knee, but to also screen out referral of symptoms and objectively examine the subject for signs of central sensitization.

Examination
The subject demonstrated mild forward head posture, an increased thoracic kyphosis and decreased lumbar lordosis. She presented with decreased weight acceptance on the left LE in stance and gait and bilateral decreased hip extension, hip flexion, dorsiflexion, and plantarflexion during gait. She had a compensated positive Trendelenberg sign on left LE, as well as bilateral pes planus, genu valgum and genu recurvatum throughout the stance phase of gait. Cardiopulmonary, integumentary, and neurological screens were negative for pathology.

A lumbar screen consisting of active ROM and over-pressure was within normal limits (WNL) in all planes of motion without reproduction of her symptoms. Hip, knee and ankle active and passive ROM measurements were measured (Table 2). Measurements of lower extremity ROM were assessed using a standard goniometer, which has been shown to be reliable and valid.35

Manual muscle testing (MMT) was used to assess gross strength of the lower extremity on a 0-5 rating scale with symptom response recorded.36 MMT has been demonstrated to be a reliable measure of muscle strength.37

Palpation revealed pain to dynamic light touch at the anterior knee. The pain was in no specific dermatomal pattern and indicative of allodynia.38 She demonstrated cutaneous tenderness to both the anterior and inferior patella. She denied specific tenderness to palpation along the tibiofemoral joint line, anterior tibia, popliteal fossa, patellar tendon or triceps surae.

Passive accessory joint mobility testing revealed coxofemoral joint anterior-posterior, tibiofemoral posterior-anterior, patellofemoral (medial, lateral, caudal, cephalic), and talocrural posterior-anterior mobility to be equal bilaterally with no reproduction of pain. Talocrural anterior-posterior mobility was deemed hypomobile bilaterally, with more restriction noted in the left lower extremity and no reproduction of pain. Patellofemoral mobility was examined with the subject in supine, and found to be equal and pain free bilaterally. Interestingly, while only subtle hypomobility was noted bilaterally at the tibiofemoral joint, posterior translation of the left tibia on the femur into approximately fifty percent of the joint resistance reproduced her anterior knee pain.

Table 2. Initial examination findings

<table>
<thead>
<tr>
<th>Joint Active/Passive Range of Motion¹</th>
<th>Left</th>
<th>Right</th>
<th>Pain Response</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hip</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion</td>
<td>WNL</td>
<td>WNL</td>
<td>--</td>
</tr>
<tr>
<td>External Rotation</td>
<td>WNL</td>
<td>WNL</td>
<td>--</td>
</tr>
<tr>
<td>Internal Rotation</td>
<td>WNL</td>
<td>WNL</td>
<td>--</td>
</tr>
<tr>
<td><strong>Knee</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion</td>
<td>135°/140°</td>
<td>135°/140°</td>
<td>anterior knee</td>
</tr>
<tr>
<td>Extension</td>
<td>0°/+5°</td>
<td>0°/+10°</td>
<td>--</td>
</tr>
<tr>
<td><strong>Ankle</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dorsiflexion</td>
<td>-10°/0°</td>
<td>10°/20°</td>
<td>--</td>
</tr>
<tr>
<td>Plantarflexion</td>
<td>40°/60°</td>
<td>40°/60°</td>
<td>--</td>
</tr>
<tr>
<td><strong>Manual Muscle Testing³⁶</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Hip</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion</td>
<td>4/5</td>
<td>5/5</td>
<td>_</td>
</tr>
<tr>
<td>Abduction</td>
<td>3+/5</td>
<td>4/5</td>
<td>--</td>
</tr>
<tr>
<td>Adduction</td>
<td>4/5</td>
<td>5/5</td>
<td>_</td>
</tr>
<tr>
<td><strong>Knee</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion</td>
<td>4/5</td>
<td>5/5</td>
<td>anterior knee</td>
</tr>
<tr>
<td>Extension</td>
<td>4/5</td>
<td>5/5</td>
<td>anterior knee</td>
</tr>
</tbody>
</table>

¹Tested in supine

WNL= within normal limits
while anterior translation of the femur on tibia did not. Knee special tests including the Lachman's test, Anterior drawer test (for ACL deficiency), Varus/Valgus stress tests and McMurray's test were all negative bilaterally.

Subjective outcomes were measured using the Kujala Anterior Knee Pain Scale (Kujala Scale),\(^{39}\) Numeric Pain Rating Scale (NPRS),\(^{40}\) Global Rating of Change (GROC),\(^{41}\) and the Fear Avoidance-Belief Questionnaire (FABQ).\(^{42}\) The Kujala Scale is a tool used to measure the function and amount of pain that a subject experiences while performing everyday activities. This outcome measure, used in both male and female populations 18-40 years old in a non-specific knee diagnostic,\(^{43}\) population, has been demonstrated to be both reliable and valid.\(^{44}\) The thirteen question, self-administered questionnaire, scores from 0-100, with higher scores signifying lower levels of pain during functional activity.\(^{39}\) An increase of at least 8-10 points on the Kujala scale represents clinically meaningful improvements in the subject's perceived pain during functional activity.\(^{44}\) The NPRS is an 11 point scale that has shown to be a valid and reliable assessment of self-reported pain in chronic pain populations.\(^{40}\) The subject reported the NPRS for current, worst and best pain in the last 24 hours, as well as pain after completing each trial of the step down test. A decrease of at least 1.2 points on the NPRS in subjects with PFPS represents clinically meaningful improvement in the subject's perceived level of pain.\(^{45}\) The GROC score was used to determine the subject's perception of overall improvement. This is a 15 point likert scale ranging from -7 (a very great deal worse) to +7 (A very great deal better). The GROC has high face validity and is used as a reference standard for many other outcome measures\(^{41}\) and demonstrates correlations to subject satisfaction, other self-reported functional scales, and physical performance testing.\(^{41}\) An increase in three points is estimated to represent a clinical meaningful improvement using the GROC.\(^{46}\) The FABQ was used to quantify the level of fear in relationship to pain at work (W) and during physical activity (PA). Higher scores indicate higher levels of fear avoidance-belief and the FABQ demonstrated good reliability in chronic low back pain populations.\(^{42}\) With modification (substituting “knee” for “back”), the FABQ and has shown to be a strong predictor of pain and functional outcomes in subjects with a patellofemoral diagnosis.\(^{47}\) While there is no current minimal clinically important difference (MCID) for the FABQ in subjects with PFPS, lower scores indicate a reduction in fear avoidance-beliefs.

Pressure pain threshold (PPT) was assessed utilizing a pressure algometer (Wagner FPX Series, 1 centimeter [cm]² rubber tip) to determine change in mechanical deep tissue sensitivity pre and post-treatment. The subject was asked to identify the most painful site, which was one cm inferior to the patella which was used as a standard reference at each subsequent session for measurement (Figure 1). PPT was measured as previously described.\(^{44}\) Specifically, each measure was taken three times with 30 second intervals between each measurement, with the average of the three measures recorded.\(^{48}\) While not studied specifically in PFPS populations, pressure algometry has shown good reliability in assessing treatment effect in subjects with knee osteoarthritis,\(^{48}\) myofascial pain,\(^{49}\) and patellar tendinopathy.\(^{50}\) There is currently no published MCID for pressure pain threshold in subjects with PFPS. Lowered PPT is a measure of deep tissue hyperalgesia indicating a facilitation of nociceptive pathways\(^{51}\) and is a common finding in other chronic conditions such as patellar tendinopathy,\(^{50}\) osteoarthritis of the knee\(^{52,53}\) and whiplash disorder.\(^{54}\)

In the Step Down Test, to record functional performance, the subject was instructed to step down from a six-inch step, with the descending limb contacting the floor with the heel and then returning to the step. While the test formally uses an eight-inch step, this subject was tested on a six-inch step secondary to availability in the clinic. The number of repetitions were recorded bilaterally in a 30 second time period along with a subjective report of pain reproduction (using the NPRS) after the completion of the 30 second step down interval. This test has demonstrated high specificity\(^{5}\) along with good intra-rater reliability\(^{5}\) for subjects with patellofemoral pain. The subject held onto the railing bilaterally for support and was cued to not push-off through the upper extremities in order to standardize this procedure each time. While an MCID for the step down test does not currently exist to this author's knowledge, the NPRS was used for subjective complaints of pain

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after the step down test was completed, and as previously mentioned it has a MCID of 1.2 points.45

Clinical Impression II
While the subject met common physical diagnostic criteria for PFPS such as hip/quadriceps weakness and diffuse tenderness at the anterior and inferior patella,6,27 she demonstrated no increase in pain with passive accessory mobility testing of the patellofemoral joint. Due to the history of pain with low load activity (i.e. walking) and absence of localized patellar tendon tenderness, a diagnosis of patellar tendinosis was deemed unlikely. Tibiofemoral anterior-posterior translation did reproduce her pain, thus implicating the tibiofemoral joint as a potential source of pain in this subject. Alternatively, tibiofemoral joint kinematics have been shown to directly affect the patellofemoral joint,56,57 potentially serving as a contributing source of PFPS. Posterior translation of the tibia on the femur has been shown to increase the posterior orientation of the patellar tendon and patellar flexion, thus increasing patellofemoral compression.58 As contact of the patella on the femur begins at 20 degrees of knee flexion and increases as the knee is flexed,56 it can be argued that the tibia on femur posterior translation at 45 degrees of knee flexion would affect the patellofemoral joint resulting in increased anterior knee pain during examination. Due to the presence of anterior knee allodynia and decreased PPT, it was hypothesized that a component of her pain may have also been centrally mediated.59,60 Due to the above findings, there appeared to be an indication for joint mobilization as it has been shown to modulate the central and peripheral effects of pain and function in chronic pain populations.61,62

Intervention
Subsequent treatment sessions focused on (1) pain reduction with an increase in PPTs and (2) correction of biomechanical deficits (strength deficits, joint mobility, and neuromuscular control) in order to normalize functional mobility. Pain reduction and an increase in PPT was achieved by using a Grade III tibiofemoral anterior-posterior (A-P) oscillatory mobilization on the LLE (Figure 2).63 Grade III accessory joint mobilizations are large amplitude movements performed into firm resistance or up to the limit of available joint range; they are used to treat hypomobility and modulate pain.63 A Grade III mobilization was warranted in this case as the subject presented with subtle hypomobility at the tibiofemoral joint along with pain at approximately fifty percent of the joint resistance. The subject was supine with knees in approximately 45 degrees of flexion. The subject was treated with two, eight minute bouts of joint mobilizations during visits 1-5. This mobilization dosage is similar to that used in two previous studies of subjects with chronic knee osteoarthritis.61,62 Supplemental instruction in therapeutic exercise and neuromuscular re-training was used to correct biomechanical impairments and given for her home exercise program (HEP) visits 1-5. On visit six, a Grade III A-P talocrural mobilization was used to target ankle hypomobility bilaterally and instruction in her HEP was again progressed to focus on therapeutic exercise and neuromuscular re-training. The talocrural mobilization was intended to target dorsiflexion limitations found at the initial evaluation as this may have contributed to altered biomechanics and influenced her pain. However, the mobilization resulted in no change in her pain upon functional re-assessment. No joint mobilization was used visits 7-8 and subject was progressed to balance and neuromuscular re-training both in the clinic and at home for HEP.

OUTCOMES
The subject attended eight physical therapy sessions over the course of eight weeks. Self-reported outcome measures (GROC, NPRS, Kujala scale, FABQ) were recorded at the initial evaluation and prior to intervention at every return appointment (Table 3). PPTs and the Step Down test (number of steps and NPRS after completion of the test) were recorded
pre-joint mobilization treatment and post-joint mobilization treatment for Visits 1-6 and pre-therapeutic exercise and post-therapeutic exercise for Visits 7-9 (Figure 3, 4 and 5.). The subject demonstrated positive post-treatment responses in pain (NPRS), function (Step Down Test), and central processing of pain (PPT). However, post-joint mobilization within session improvements (sessions containing solely joint mobilization) appeared greater in comparison to sessions which contained exercise alone. With the combination of both joint mobilization and therapeutic exercise, this subject demonstrated improvements in PPTs (119 kPa to 386 kPa), steps (11 to 40), FABQ (6/24 to 2/24 PA, 31/42 to 5/42 W), Kujala scores, GROC scores, and NPRS from initial evaluation to discharge, all of which met the MCID. At the conclusion of physical therapy care, the subject demonstrated improvements in her Kujala scores,

Table 3. Patient-reported Outcome measures

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>GROC</th>
<th>NPRS</th>
<th>Kujala</th>
<th>FABQ(PA)</th>
<th>FABQ(W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Evaluation</td>
<td>--</td>
<td>6</td>
<td>53</td>
<td>6/24</td>
<td>31/42</td>
</tr>
<tr>
<td>Visit 2</td>
<td>+2</td>
<td>6</td>
<td>53</td>
<td>6/24</td>
<td>13/42</td>
</tr>
<tr>
<td>Visit 3</td>
<td>+4</td>
<td>2</td>
<td>63</td>
<td>3/24</td>
<td>12/42</td>
</tr>
<tr>
<td>Visit 4</td>
<td>+5</td>
<td>2</td>
<td>53</td>
<td>5/24</td>
<td>3/42</td>
</tr>
<tr>
<td>Visit 5</td>
<td>+5</td>
<td>2</td>
<td>65</td>
<td>4/24</td>
<td>5/42</td>
</tr>
<tr>
<td>Visit 6</td>
<td>+5</td>
<td>2</td>
<td>68</td>
<td>2/24</td>
<td>5/42</td>
</tr>
<tr>
<td>Visit 7</td>
<td>+5</td>
<td>2</td>
<td>67</td>
<td>2/24</td>
<td>5/42</td>
</tr>
<tr>
<td>Visit 8</td>
<td>+5</td>
<td>2</td>
<td>67</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Follow up (2 months)</td>
<td>+5</td>
<td>0</td>
<td>--</td>
<td>0/24</td>
<td>6/42</td>
</tr>
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GROC= Global Rating of Change (scale = -7 to +7)
NPRS= Numeric Pain Rating Scale (Current; 0-10)
Kujula= Kujala Anterior Knee Pain Scale; higher score is better
FABQ= Fear Avoidance and Belief Questionnaire (PA) = Physical Activity
FABQ= Fear Avoidance and Belief Questionnaire (W) = Work

Figure 3. Pain Pressure Threshold (PPT) in kilopascal (kPa) Pre and Post Treatment Left Lower Extremity (LLE). Red: Pre-Treatment PPT Measurement Blue: Post-Treatment PPT Measurement.

Figure 4. Pain (Numeric Pain Rating Scale (NPRS)) Pre and Post Treatment in Left Lower Extremity (LLE).

Figure 5. Step Down Test Pre and Post Treatment in Left Lower Extremity (LLE).
NPRS, GROC, FABQ, PPTs and step down test when compared to the initial evaluation. At two months follow up, the subject was called and reported she was satisfied with her current state and continued to have improvement in functional activity concerning dancing and walking with a reported NPRS of 0/10, GROC of +5, and FABQ PA of 0/24 and W 6/42.

DISCUSSION
This case describes the successful use of tibiofemoral joint mobilization in a subject with chronic PFPS. The findings in this case highlight the fact that tibiofemoral dysfunction may be a source of PFPS and thorough examination of articulations adjacent to the patellofemoral joint may be critical for best management. The case also supports the notion that joint mobilization can be successfully used for the treatment of chronic LE pain in those with PFPS who may have a component of central sensitization to their pain. Similar results were demonstrated in previous research concerning subjects with chronic knee OA.61,62

The current results may be attributed to biomechanical correction, modulation of neurophysiological pain mechanisms and/or a combination of both as the subject’s pain presentation was suspected to be multifactorial. Biomechanically, an anterior-posterior mobilization of the tibiofemoral joint can be assumed to have an effect on the motion of the patella as kinematics of the lower extremity have been thought to influence the patellofemoral joint 57 resulting in decreased anterior knee irritation. Targeting structures that needed to be stretched and strengthened (i.e. joint capsule, muscles, adjacent tissues) may have also led to a correction of biomechanical imbalance and decreased anterior knee pain as therapeutic exercise has already been shown to be effective in the treatment of PFPS for pain and function.11-16 Alternatively, the source of pain may have been the tibiofemoral joint masquerading as patellofemoral joint dysfunction. Of note, factors implicating PFPS do not necessarily require patellofemoral passive accessory joint findings nor exclude tibiofemoral joint impairments.8,57 While PFPS is thought to be largely due to biomechanical deficits (Table 4), emerging evidence has also suggested a neurophysiological component to PFPS.64-66 Expanded pain sensitivity both locally and at distal sites66, have been identified in adolescent females with PFPS using PPT, possibly indicating the presence of central sensitization of nociceptive pathways.59,60 Similar findings have been found in subjects with chronic knee osteoarthritis and these findings are theorized to have an effect on the subject’s

<table>
<thead>
<tr>
<th>Table 4. Biomechanical Contributors to PFPS</th>
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<tbody>
<tr>
<td><strong>Proximal</strong></td>
</tr>
<tr>
<td>Decreased hip abductor, extensor, external rotator strength</td>
</tr>
<tr>
<td>Altered gluteus medius and maximus neuromuscular activity</td>
</tr>
<tr>
<td>Muscle strength imbalances between the vastus medialis and lateralis</td>
</tr>
<tr>
<td>Dysfunction in VMO-VL onset timing and strength</td>
</tr>
<tr>
<td>Hamstring and quadriceps flexibility/strength deficits</td>
</tr>
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</table>
subsequent knee stability and function. As the subject met all of the subjective and functional diagnostic requirements of PFPS and other potential pathologies were ruled out through imaging and physical examination, the authors hypothesized that this subject presented with PFPS along with a component of central sensitization. As subjects with anterior knee pain have also been shown to have significant quadriceps inhibition assumed to be secondary to pain, manual therapy interventions have been proposed for improving activation. Since peripheral and central effects on pain have been demonstrated following graded mobilization of the knee, the authors hypothesized that local joint mobilization of the tibiofemoral joint may have decreased subject pain and quadriceps inhibition. As therapeutic exercise has already been shown to be effective in the treatment of PFPS for pain and function, the authors selected specific exercises for her HEP to maintain within session carryover and increase functional activity.

Regardless of the exact mechanism of our subject's results, improvements in both biomechanical and neurophysiological outcome measures were observed. While within session changes have been shown to lead to between session changes, it has recently been shown that positive within session and between session results are also important for prognostic carryover concerning pain and function. Sessions consisting of joint mobilization appeared to have significant reductions in pain and a greater increase in steps taken during the step down test along with greater change in PPTs when compared to sessions that only included the use of therapeutic exercise (Figure 3, 4 and 5.). Concerning the NPRS, FABQ, and Kujala scores, similar trends in the data applied. While the NPRS and Kujala scores demonstrated improvements in patellofemoral pain and function, the FABQ revealed an improvement in the subject's self-reported fear avoidance over the course of treatment. Her PPT also improved. As increased fear avoidance has been correlated to centrally mediated pain among subjects with chronic pains, the positive improvement both on the FABQ and the PPT score indicate a modulation in the central processing of her pain.

There were several limitations regarding this case report. The findings from a case report cannot be generalized to all subject populations and high quality randomized control trials are needed to examine the purported mechanisms suggested for improvement following the use of joint mobilization in those with chronic PFPS. While the subject was blinded to the PPT algometer readings, she was not blinded to the purpose of recording the data. This could have led to the subject trying to endure more pain in order to please the clinician and achieve better outcomes. However, it should be noted that these positive results demonstrated carry-over throughout the eight treatment sessions. The subject was informed that the data concerning the case would be submitted for publication.

CONCLUSION

This case report highlights the successful management of an individual with chronic PFPS using mobilization of the tibiofemoral joint supplemented by a therapeutic home exercise program. While there is paucity in the literature concerning the use of tibiofemoral joint mobilization for chronic PFPS, it should be considered as this case highlights the positive effects on both immediate and long term pain, function, and central processing of pain in a case where a central mediated component of pain may be present.

REFERENCES


ABSTRACT

Rotator cuff pathology can contribute to shoulder pain and may affect the performance of sport activities, work, and activities of daily living. The partial articular supraspinatus tendon avulsion (PASTA) lesion represents a very common type of rotator cuff pathology seen in rehabilitation. When conservative treatment fails, surgery is generally required. Success of recovery depends on several factors, including: repair techniques, healing process related to timing, rehabilitation programs, and patient compliance with home exercises. To date, most treatment modalities and rehabilitation programs are based on clinical experience rather than scientific evidence. Therefore, the purpose of this clinical commentary is to provide an overview on the PASTA lesion, discuss the common treatment approaches adopted to date and to propose a rehabilitation program based on the available scientific evidence.

Level of Evidence: 5

Keywords: Rehabilitation, rotator cuff, shoulder
INTRODUCTION AND BACKGROUND
Partial-thickness rotator cuff tears (PTRCTs) are a common cause of shoulder pain, limitations in activities of daily living (ADL), and time off from work. It has been reported that the incidence of PTRCTs is between 17% and 37% in the population and up to 80% in patients in their eighth decade of life. PTRCTs were difficult to diagnose before magnetic resonance imaging (MRI) and shoulder arthroscopy, therefore most scientific research has focused on full-thickness rotator cuff tears (FTRCTs). PTRCTs are generally classified according to their location and arthroscopic appearance. The partial articular supraspinatus tendon avulsion (PASTA) lesion is a type of PTRCT and is far more common than bursal-sided or intratendinous partial tears. According to Gratsman and Milne PASTA lesions comprise 91% of all PTRCTs. PASTA lesions are commonly found in overhead athletes, younger people and patients who smoke. Although the natural history of PASTA lesions remains unclear, this variety of tendon disruption is generally associated with pain and disability and it has been shown that 53% of PASTA lesions tend to enlarge. Both surgical techniques and postoperative rehabilitation are essential to optimize recovery. However, significant variations exist between surgical options and rehabilitation protocols. Therefore, the purpose of this clinical commentary is to provide an overview on the PASTA lesion, discuss the common treatment approaches adopted to date and to propose a rehabilitation program based on the available scientific evidence.

ANATOMY
The glenohumeral is a delicate ball-and-socket joint. Movement of the shoulder complex can be grossly divided into scapulothoracic and glenohumeral motion. The scapula provides a bony base for muscle attachments and load transfer. Abnormal scapulothoracic motion may be a factor that increases the risk of impingement syndrome and PTRCTs. Stability of the glenohumeral joint is provided by the joint capsule, ligaments, bony anatomy, and the negative pressure within the joint space. The rotator cuff provides compression of the humeral head on the scapula, increasing the stability of the joint. The muscles that form the rotator cuff are: supraspinatus, subscapularis, teres minor and infraspinatus. The supraspinatus muscle originates on the posterior aspect of the scapula, superior to the spine and inserts directly on the greater tuberosity of the humerus close to the articular surface. The lateral insertion of the supraspinatus is overlapped by the tendon of the infraspinatus, fusing the two into one structure. The subscapularis is the largest muscle-tendon unit. It originates on the anterior aspect of the scapula and inserts on the medial aspect of the biceps groove. The teres minor originates on the posterior surface of the axillary border of the scapula and inserts on the inferior-posterior aspect of the greater tuberosity of the humerus. The infraspinatus lies on the posterior aspect of the scapula. It originates inferior to the spine of the scapula and inserts on the greater tuberosity of the humerus, wrapping around the posterior aspect of the supraspinatus tendon. The subscapularis provides anterior stability and internal rotation motion to the humerus while the supraspinatus, teres minor and infraspinatus make up the posterior aspect of the rotator cuff which is responsible for abduction and external rotation of the shoulder.

PATHOPHYSIOLOGY
Mechanisms leading to rotator cuff injury are still under debate. Generally, PTRCTs occur at the junction of the inferior part of the supraspinatus and the superior part of the infraspinatus, leading to the PASTA lesion. Most clinicians think that intrinsic, extrinsic and traumatic factors are all possible causes of PASTA tears. Among the intrinsic factors, changes in rotator cuff vascularity and metabolic changes associated with aging seem to play an important role. Some authors have shown that the size of the vessels are larger and more prevalent on the bursal side of the rotator cuff while the articular surface of the rotator cuff is relatively hypovascular. Results of histological studies have also shown that collagen is thinner and not as well organized on the articular surface of the rotator cuff when compared to the bursal surface of the rotator cuff, leading some authors to believe that the articular cuff is only one half as strong as the bursal counterpart. Alternatively, some authors that believe extrinsic and traumatic factors are primary contributors to the development of PASTA lesions. Shear stresses that affect the supraspinatus tendon due to narrowing of the
coracoacromial arch (extrinsic impingement) have been identified as a plausible cause of rotator cuff injury as they may generate a laminated disrepair of the surfaces of the cuff. Repetitive microtrauma may also cause articular surface tears especially when associated with overhead activities. Internal impingement as termed by Walch and colleagues has been demonstrated as another possible reason for the PASTA lesion in overhead athletes. It occurs due to the repetitive contact of the articular surface of the supraspinatus and infraspinatus tendons with the posterosuperior part of the glenoid during arm abduction and lateral rotation. Many authors believe that anterior shoulder micro-instability is contributory to internal impingement and to PASTA lesions although rotator cuff injuries have been demonstrated in otherwise stable shoulders.

CLINICAL DIAGNOSIS
Clinical diagnosis of PASTA lesion can be difficult as not all PASTA lesions are symptomatic. Pain is generally present in the arc of motion between 60° and 120°. Some authors have reported that PTRCTs can be more painful than FTRCTs. It has also been reported that pain may be correlated with increased levels of Substance P in the subacromial bursa rather than the extent or the depth of the tear of the tendon. Pain is generally provoked by resisted abduction with the shoulder positioned at 90° of abduction, in the plane of the scapula and in either internal or external rotation as in the empty/full can test. However, when considering pain as a symptom for detection of supraspinatus tendon tear Itoi et al suggest the utilization of the full can test. A positive lag test should make the clinician think of a FTRCT rather than PASTA lesion. Impingement tests such as those proposed by Neer and Hawkins may be positive. If impingement tests are positive, the internal rotation resistance strength test may be utilized to help distinguish between outlet (Neer) and non-outlet (internal) impingement. With the shoulder positioned at 90° of abduction, at approximately 80° of external rotation and with the elbow bent at 90°, external and internal rotator muscles are tested with a resisted isometric contraction. A sign of apparent weakness of internal versus external rotation of the shoulder is considered positive for non-outlet (internal) impingement. For the overhead athlete, the clinician should also look for subtle signs of shoulder instability. Apprehension and relocation tests may be used during the examination although the presence of pain without apprehension is an unreliable finding for shoulder instability, as it is quite common in many other shoulder disorders. Physical examination findings for PASTA lesion can be non-specific and difficult to distinguish from other shoulder conditions. It has been reported that 30% of PASTA lesions occur concomitantly to other shoulder disorders. As a result, imaging modalities are essential for definitive diagnosis of the PASTA lesion.

IMAGING
A combination of imaging modalities is generally used for the assessment of PASTA lesion as no single imaging study has been shown to be particularly accurate. Radiographs, including an anteroposterior view of the shoulder, an axillary lateral view and a supraspinatus outlet view are sometimes used. However, they are more appropriate for assessing acromioclavicular lesions or glenohumeral disorders than PASTA lesions. Ultrasound imaging is an appropriate technique for assessment of rotator cuff tears and has been proved to be valuable for diagnosis of both FTRCTs and PTRCTs. It should be considered the best option considering safety, cost, and accuracy for FTRCTs. However, sensitivity of ultrasound imaging for PTRCTs is lower than magnetic resonance imaging (MRI).

Although MRI techniques have recently improved the ability to detect subtle rotator cuff tendon abnormalities, findings of the MRI should be interpreted cautiously as false-negative results when compared to arthroscopy have been reported in a previous study. MRI has demonstrated high sensitivity and specificity (0.90) for FTRCTs, but poorer sensitivity for detection of partial rotator cuff tears. The clinical relevance of MRI is further limited as many individuals older than 40 years of age who demonstrate abnormal rotator cuff findings on MRI are symptom-free at the clinical evaluation. Thus, signs of partial rotator cuff tear on MRI could be an incidental finding in symptomatic as well as in asymptomatic patients.
CLASSIFICATION
PTRCTs are defined as definite disruption of fibers of the tendon and not simply fraying, roughening, or softening of the tendon surface. Tears can be classified with regards to the involved tendon, the location (articular, bursal or intratendinous) and the size, represented as the percentage of the tendon thickness torn or the vertical component relative to the tendon thickness. Although there is not a classification system specifically designed for PASTA lesions, two main rotator cuff tear classification systems are generally utilized. Ellman described the lesions of the rotator cuff tendon according to the location of the tear (articular surface, bursal surface and intratendinous) and the extension of the tear. Grade 1 tears are smaller than 3 mm, Grade 2 tears are between 3 and 6 mm, while Grade 3 tears involve more than one half of the cuff tendon thickness (generally more than 6 mm). Snyder and colleagues have adopted a similar classification system based on the location of the tear (A = articular surface, B = bursal surface, C = complete) and on the arthroscopic appearance (grades from 0 to 4). Grade 0 represents a normal cuff. In Grade 1 there is minimal superficial fraying in an area smaller than 1 cm. Grade 2 signifies fraying and failure of the rotator cuff tendon in an area smaller than 2 cm. In Grade 3 there is fraying and fragmentation of the entire surface of the tendon. Grade 4 tears are characterized by a stable flap tear that often encompasses more than a single rotator cuff tendon that is larger than 3 cm.

The management of PASTA tears remains controversial. Most surgeons agree with the concept that treatment of PASTA lesions varies according to the stage and the pathology and should begin with conservative treatment. However, when more than one half of the thickness of the supraspinatus tendon is involved (Ellman or Snyder Grade 3) surgical repair in symptomatic patients is indicated. The final choice informing treatment for PASTA lesions should consider clinical evaluation, imaging findings, and classification of the tear. Treatment options are either conservative or surgical.

CONSERVATIVE TREATMENT
Treatment should start with physical therapy. Rest or activity modification with the avoidance of the movements that elicit pain should be included from the early stage of the management. Oral non-steroidal anti-inflammatory drugs may be beneficial for reduction of pain and inflammation although they are less effective than corticosteroids in terms of pain reduction. However, it is important to note that both non-steroidal anti-inflammatory and corticosteroid drugs may have deleterious effects on long-term tendon healing.

Although commonly utilized to manage rotator cuff tears, many physical modalities and manual therapy techniques lack validated research that justifies their use. Laser therapy has been widely studied on several tendinopathies with mixed results. It has been suggested to be beneficial for shoulder tendinopathy and superior to therapeutic ultrasound in terms of pain reduction. Therapeutic ultrasound seems to help reverse the tendinosis and appears beneficial for calcific tendonitis of the supraspinatus. However, it has been shown to be no more effective than placebo for soft tissue disorders of the shoulder. Transcutaneous electrical nerve stimulation (TENS) for shoulder disorders has not been studied as much as laser and therapeutic ultrasound. It has been shown to be effective for post-surgical pain, but there is paucity of evidence regarding its effectiveness for PASTA lesions.

The use of joint mobilization techniques such as accessory movements and joint glides can be applied to assist in decreasing pain, muscle guarding, and restoring range of motion (ROM) deficits. Although joint mobilizations and mobilizations with movement have been found to not be superior to supervised exercise and to physician advice, manual therapy techniques to the glenohumeral joint seem to have positive effects across all painful shoulder conditions. A recent review investigating adults suffering of non-specific shoulder pain demonstrated that spinal manipulations and spinal mobilizations also help improve self perceived recovery when compared to usual care. Myofascial massage of trigger points located in the shoulder girdle soft tissues seems to be more effective than placebo in terms of pain and shoulder function in patients suffering from shoulder disorders.

Once pain is manageable, physical therapy should proceed to restoring ROM deficits and strengthening of relevant muscle groups with particular focus on...
the scapular stabilizers and rotator cuff muscles, initially avoiding those exercises that maximally activate the supraspinatus muscle-tendon unit. Stretching techniques should be performed in those patients with total arc of motion limitations, particularly in the overhead athletes with glenohumeral internal rotation deficits due to posterior capsule tightness.

Restoration of neuromuscular coordination and core stability is also beneficial and important to restore the mechanisms of load transfer and for the avoidance of scapulothoracic dyskinesis. It is in fact well known that upper extremity motion occurs with consistent synergistic muscle activation patterns in the leg and trunk. Therefore, it is important to remember that scapular muscle force couples requires core strength and facilitation by the activation of the whole kinetic chain.

As there is not a treatment algorithm for PASTA lesions and no evidence regarding the evolution of non-operative treatment, the outcome of conservative treatment is unknown. However, the results of one study indicate that there was a progression of the rotator cuff tear in 80% of the patients who were treated non-operatively. This would suggest that surgical treatment for PASTA lesion should be considered.

**SURGICAL TREATMENT**

As spontaneous healing of PTRCTs is unlikely or poor, surgery is often required. Surgical treatment of PTRCTs generally involves one of the following: arthroscopic debridement of the tear, debridement with acromioplasty, and rotator cuff repair with or without acromioplasty.

There is controversy whether debridement with or without acromioplasty is a sufficient treatment option for PTRCTs. Budoff et al reported excellent results while more recent investigations have shown that although pain may get better, a large portion of PTRCTs evolve to deterioration of the lesion leading to FTRCTs.

If a significant articular-sided tear is present and there is a significant healthy portion of the bursal side of the tendon still intact, some surgeons may prefer to repair the tear by making a small perforation in the rotator cuff as a method to place medial anchors. This is a safe and effective modern arthroscopic technique that restores the anatomy of the damaged rotator cuff by securing the articular side of the tendon back to its original footprint while preserving the undamaged bursal side of the tendon. Attempts to preserve the bursal side footprint of the rotator cuff as in the trans-tendon repair technique has been shown to enhance healing and clinical outcomes.

In some cases when only 25% of supraspinatus tendon remains attached to the bone, surgeons may prefer to complete the tear from a PTRCT to a FTRCT and treat it using suture anchors. However, when conversion to FTRCT is performed, there is a high rate of re-tear. It may be due to formation of scar tissue and lack of restoration of fibro-cartilaginous connection in the bone-tendon attachment. Regardless the surgical approach; post-surgical rehabilitative management is key.

**POST-SURGICAL TREATMENT**

In addition to the surgical technique adopted by the surgeon, knowledge of the histology and biology of the healing process is paramount as it guides the therapist to rehabilitation programs that optimize healing rate and improve clinical outcomes. Authors suggest that tendon healing consists of three overlapping phases: inflammation, proliferative/repair and remodeling. Following surgical tendon-to-bone fixation, there is an inflammatory phase where type-III collagen synthesis is initiated over the surgery site. After a few days, growth factors induce cellular proliferation and matrix deposition. After approximately six weeks, the tissue begins remodeling where there is organization of the scar tissue and a higher proportion of Type-I collagen is synthesized. However, remodeling repair tissue does not reach maximal tensile strength before 12-16 weeks after surgery. It is important to remember that during the rehabilitation program progression, the mechanical proprieties of the repairing fibrous tissue are weaker than the native tissue and that it prone to failure and re-tear may occur in up to 12% of the cases.

The following sections report the evidence of common post-operative treatment options and present
an evidence-supported program for the post-surgery treatment of PASTA lesions.

**Immobilization and early versus delayed range of motion**

Post-surgical stiffness is one of the most common complications occurring after rotator cuff surgery regardless of the surgical technique adopted and it is likely linked to prolonged immobilization. However, research results supporting immobilization timeframes, or early or delayed ROM after surgical repair of rotator cuff tears are still controversial. Animal studies indicate that immobilization may reduce the tension over the rotator cuff repair and may help improve the collagen orientation, although it can cause deterioration of a tendon as it decreases the protein synthesis and increases the collagenase activity.

The optimal timing for initiation of ROM remains under debate. There are some authors that, regardless of the prolonged healing process required for a tendon-to-bone repair, suggest that early mobilization can be safely applied. Early mobilization is also considered to help recover ROM more rapidly in those patients who undergo arthroscopy for cuff repair. Other authors suggest that there is no difference between early and delayed joint mobilization after arthroscopic cuff repair for stiffness and ROM and that prolonged immobilization up to six weeks or delayed ROM is not a concern for joint stiffness.

Research has been extensively conducted on repair of FTRCTs but not for PASTA lesions, therefore, there are no recognized indications regarding immobilization and ROM timing. However, patients with PASTA lesions should be mobilized as early as possible as it has been suggested that arthroscopic repair of PASTA lesions is a risk factor for post-surgery stiffness.

**Cryotherapy**

Cryotherapy is generally used post-surgery to decrease pain, inflammation and swelling. Adie et al. examined the effects of cryotherapy after total knee arthroplasty, showing the benefit of reduction of blood loss and pain although the improvement may not have been clinically significant. Authors have also shown that the use of cryotherapy after shoulder surgery decreases the need for narcotics and that patients are better able to tolerate rehabilitation and to return to normal sleeping patterns. Although the use of cryotherapy is still under debate, most believe it advisable for use it in the immediate post-surgical timeframe.

**Regenerative techniques**

Tissue regenerative strategies involving the use of mesenchymal stem cells, growth factors and platelet rich-plasma may be potentially effective therapies to enhance bone-to-tendon healing after shoulder surgery. Promising results have been reported in both animal and in vitro studies including: a better orientation of the fibrocartilage fibers, improvement of mechanical resistance and tendon healing. Ellera Gomes et al. published the only investigation on the effects of stem cells in rotator cuff tears in humans to date. They investigated 14 patients with a complete tear of the rotator cuff repaired in a trans-osseous fashion thorough a mini-incision augmenting the suture with stem cells. At 12 months, according to clinical and magnetic resonance findings, 12 of the 14 tears had healed. However, the use of these new augmentation techniques on rotator cuff tears should still be considered experimental because both surgical costs and lack of validated basic and clinical research.

**PROPOSAL OF A POST-SURGERY PROGRAM FOR PASTA LESIONS**

As every PASTA lesion and every patient is unique, several considerations must be taken into account when building a rehabilitation program for optimal results. The rehabilitation program should be evaluation-based and should consider size of the tear, surgical technique, healing process timing, surgical findings, patient age, and the patient’s goals. Therefore, the following five-phased program serves as a guideline that should be individualized for each case and adapted to each patient.

**Phase I**

The main goals of this stage are to enhance the structural repair, control pain and inflammation, increase ROM, and prevent muscular atrophy. During this phase, a sling should be worn for about two weeks in order to maintain integrity of the repair site and
to encourage rotator cuff healing\textsuperscript{116} and it should be removed only for self-care and wound cleansing. It has been suggested that the shoulder should be immobilized in the scapular plane at 45° of shoulder abduction as this position enhances regional blood flow and minimizes the passive tension on the repair site by reducing the distance between the origin and the insertion of the supraspinatus muscle.\textsuperscript{117} It is important to keep good mobility and strength in the elbow, wrist, and hand while initiating a preliminary rehabilitation program. As collagen deposition increases 10 days after surgery and reaches a plateau at about 56 days after surgery,\textsuperscript{118} passive mobilization that excessively stresses the newly formed collagen network should be avoided. However, passive motion in a controlled manner within a safe ROM is beneficial as it positively affect the orientation of the collagen fibers \textsuperscript{90,91,119,120} and may minimize potential joint stiffness.\textsuperscript{121} Exercises should be passive initially and then assisted by tools such as a wand. An example of passive ROM consists of repetitions of closed kinetic chain (CKC) shoulder flexion with the support of a table (Figures 1 A-B). While standing in front of a table, place the hands on the table and step away as far as comfortable, hold the position and go back to the initial position. CKC exercises increase joint approximation, stimulation of mechanoreceptors and dynamic stability of shoulder complex,\textsuperscript{122,123} resulting in an improvement of kinesthesia.\textsuperscript{124} Pendulum exercises are also usually utilized in this phase. Standing with the trunk bent and the good arm placed on a table for stability, the patient swings the affected arm while drawing circles (Figure 2). An electromyographic analysis demonstrated that the activation of the supraspinatus muscle is less than 10% when small diameter circles are performed.\textsuperscript{125}

Manual therapy including glenohumeral distractions and anterior and posterior glides to the glenohumeral joint with the shoulder in the resting position can be used to restore ROM since glides have been shown to be safe during the initial stages of rehab, without altering stress on the repaired supraspinatus tendon.\textsuperscript{126} Shoulder function and pain may also be improved with sternoclavicular joint mobilization.\textsuperscript{127} Mobilization of the scapula may be useful in the initial stages as it may help break down adhesions and release muscle guarding, improving general function of the shoulder and decrease pain. However, it does not appear to be more effective than placebo and supervised exercise.\textsuperscript{128, 129}
Aquatic therapy (the use of the water for rehabilitation purposes), can be safely introduced once the stitches have been removed and the surgery wound has healed completely. This rehabilitative technique provides a supportive medium, facilitates ROM, and is a method to light initiate resistance training. Moreover, various exercises performed in water demonstrate less rotator cuff electromyographic activation than when performed on the land, aquatic therapy offers a safe environment to perform movements without compromising the healing process of the repair site.

During this phase, attention should be also placed on a good postural awareness and control of the spine and of the scapula by activation of the scapular musculature. Scapular retractions and depressions are appropriate exercises to activate the shoulder girdle musculature with minimal rotator cuff recruitment. To improve muscle activation awareness, it is advisable to use an electromyographic biofeedback. Patient education is of the utmost importance for this phase of the rehabilitation program, as the patient may need to carry out the prescribed exercises at home with minimal supervision of the therapist.

Criteria to progress to the next phase are: minimal discomfort when the shoulder is unsupported, pain-free passive flexion to 130°, pain-free passive internal and external rotation to 50° in the scapular plane.

Phase II

The patient may be ready for this phase at 3-4 weeks post-surgery although it may be delayed depending on the quality and size of the repair. During this phase the healing process is increasing the tensile strength of the repair site which is now able to withstand higher mechanical loads. Exercises during this phase are performed in order to attain full pain-free ROM, improve neuromuscular control, restore

Figure 2. *Pedulum exercise with the supporting arm on a table.*

Figure 3. *Low rows. The patient is standing with one hand on the edge of a table and pushes backwards retracting and depressing the scapula.*
normal patterns of muscle contraction and to return to normal ADLs. The use of pulleys, canes, and active assisted ROM (AAROM) are indicated at this point to enhance movement and recover full ROM. Stretching of the pectoralis minor muscle if it restricts upward rotation of the scapula is also advisable. Submaximal isometric contractions in all planes and at multiple angles can be initiated at the stage. Activation of the scapulothoracic stabilizers should still be a major focus as it allows neuromuscular control and full pain-free ROM. Attention should be placed to the scapular retractors (rhomboids and medium trapezius muscles), scapular protractors (serratus anterior muscle) and scapular depressors (lower trapezius muscle) which are enhanced with low rows (Figure 3).

Excess upper trapezius (UT) muscle activity with decreased activation of the lower trapezius (LT) muscle has been proposed to contribute to poor posture, muscle imbalances, and several shoulder pathologies.\textsuperscript{137,138} Therefore, it is important to assess and address the LT/UT and middle trapezius (MT) muscle/UT activity ratio.\textsuperscript{139} Exercises that enhance the LT/UT and MT/UT activity ratios are side-lying external rotation with a pillow between the body and the arm\textsuperscript{140} (Figures 4 A-B), side-lying forward flexion and prone horizontal abduction with the shoulder in external rotation.\textsuperscript{139}

The serratus anterior can be activated in supine by scapular protraction in $90^\circ$ of shoulder flexion (Figures 5 A-B).

Scaption (scapular plane elevation) can be introduced at this stage to initiate recruitment of the supraspinatus muscle. Initially, it is advisable to perform this exercise with the elbow bent at $90^\circ$ to reduce excessive stress to the repair site by using a shortened lever arm (Figures 6 A-B). Next, this exercise can be progressed to the “full can” exercise (Figures 7 A-B), which is known to demonstrate high activation of the supraspinatus,\textsuperscript{17,33} minimizing the chance of subacromial impingement.\textsuperscript{141} Due to the simultaneous activation of multiple muscles, it has been suggested that scaption (full-can) exercises be implemented when preparing a patient to perform tasks that require open chain elevation beyond the shoulder level.\textsuperscript{142}

Open chain proprioceptive activities can be initiated during this stage. Examples include joint positioning and mirror repositioning for flexion.\textsuperscript{143} In supine, the noninvolved shoulder is positioned at a certain angle of flexion and then the patient tries to mirror

![Figure 4 A-B.](image)

*External rotation in side-lying. Beginning position (A) and ending position (B).*
Phase III

Phase three generally starts at 6-8 weeks post-surgery, at which time the remodeling phase is nearly complete and soft tissues are reasonably well healed, requiring less protection that during the earlier stages. Exercises during this phase are progressed and directed towards aims such as: improving strength and endurance of the rotator cuff and shoulder girdle muscles.144 Shoulder internal and external

the same angle with the involved shoulder with and then without visual clue (Figures 8 A-B). This exercise is also important for monitoring the activity of the UT during elevation tasks and avoiding the shoulder shrug position.

Criteria to progress to the next phase are: full pain-free ROM, negative impingement tests and no scapular dyskinesia during both static positions and active scaption movements.

Figure 5 A-B. Activation of serratus anterior in supine by scapular protraction. Initial position (A) and ending position (B).

Figure 6 A-B. Scapular plane (scaption) exercise with elbows bent at 90°. Initial (A) and final (B) positions.
Figure 7 A-B. "Full can" exercise. The patient elevates the arms on the scapular plane from the side (A) to 90° of flexion (B), keeping the shoulder in external rotation (thumbs up).

Figure 8 A-B. The patient positions the uninvolved shoulder (right) at certain angle of flexion (A) and then mirrors the same angle with the involved shoulder (left) (B) with and then without visual input (queue).
rotator muscles are strengthened by motions utilizing graduated elastic bands with the arm in the scapular plane and below the shoulder height. To do so, it would be advisable to use a pillow or towel roll between the upper limb and the trunk as this configuration enlarges the sub-acromial space, reducing the risk of primary impingement (Figures 9 A-D).

Strengthening of the serratus anterior muscle continues with the dynamic hug exercise as illustrated by Decker et al.\textsuperscript{146} This exercise is performed in standing, using elastic resistance and mimicking a hugging motion around a cylindrical object with the shoulder internally rotated to 45° (Figures 10 A-B). The muscle then is further strengthened via CKC.

![Figure 9 A-D. Strengthening of shoulder external and internal rotators with elastic band resistance, with a pillow between the trunk and the upper limb. Initial (A) and final (B) position for external rotators. Initial (C) and final (D) position for internal rotators.](image)

![Figure 10 A-B. Dynamic hug exercise. With the resistance of an elastic band, the patients begins the exercise with the elbows flexed, shoulders abducted and internally rotated (A). Then the patient performs an imaginary arc, while extending the elbows, until maximum protraction is attained (B).](image)
progressively introduced to improve neuromuscular control of the shoulder.

Trapezius and rhomboid muscles are also important and can be strengthened with elastic resistance (Figures 12 A-B).

To improve scapulothoracic muscular endurance, it is suggested to utilize exercises with low to moderate resistance, high repetitions (long-duration sets) and minimal rest between sets. An upper ergometer may be also beneficial. However, in order to prevent sub-acromial impingement, it should be utilized in standing, with the axis of the ergometer below shoulder level.

Biceps and triceps brachii muscles may be addressed as needed at this time with conventional biceps curls and triceps extension using free weight (isotonic) or elastic resistance.

The therapist should guide the patient during the execution of all exercises in order to avoid substitution patterns (shoulder shrug sign) and encourage proper techniques.

To maximize force generation, utilize the entire kinetic chain during upper extremity movements,
and minimize joint loads, incorporation of a core
stability-strengthening program is recommended.
Although description of specific exercises and pro-
gression is beyond the scope of this clinical com-
mentary, addressing the core is important, especially if
the patient is an athlete who wishes to go back to
sport activities.150

Progression to the last phase is possible once the
patient is pain-free with ADLs.

**Phase IV**

At about 12 weeks post-surgery, the healing process
should be complete enough to allow the healed col-
lagen to withstand increasing mechanical forces.
This phase is a progression of Phase III, including
more demanding strengthening exercises. Rotator
cuff muscles are strengthened by using internal and
external rotation with elastic resistance in more chal-
lenging positions such as: at 45° of shoulder abduc-
tion, initially, and at 90° of shoulder abduction later.

Advanced rhythmic stabilization training in open-
kinetic-chain is accomplished by the use of an oscil-
lating blade or device. The patient oscillates the
blade vertically and horizontally while maintain-
ing the shoulder in the scapular plane at about 90°
of flexion (Figure 13). Progressively, the patient is
challenged outside of the scapular plane in more
demanding positions, for example at 90° of abduc-
tion and 90° of external rotation, and eventually in
sport-specific movements.

Plyometric training is also paramount and needs
to be addressed in the late stages of Phase IV. Ply-
ometrics employ the stretch-shortening cycle with
the goals of stimulating the body’s proprioceptors
and increasing muscle recruitment over a minimal
amount of time.151 Usually the patient starts by per-
forming bilateral wall tosses and progresses to unilat-
eral throws against a rebounder with progressively
heavier weighted balls. Exercises should begin with
positions below shoulder level and progress to over-
head positions. An example of advanced plyometric
exercise for the internal rotators is performed with
the patient in supine with the arm in the 90/90 posi-
tion, and the patient catches and immediately tosses
back the weighted ball to the therapist. Such an exer-
cise can be progressed to upright positions such as
half-kneeling and standing.

**Phase V (Return to sport)**

After completing Phase IV, athletes should com-
plete an interval sport program to safely return to
competitive sport activities. Interval sport programs
should be sport specific although there should be
general exercise prescription focusing on cardiovas-
cular endurance, scapulothoracic and rotator cuff
muscle strengthening. Recurrences of injury to the
rotator cuff should attempt to be minimized there-
fore, any reasons thought to facilitate PASTA lesions,
such as anterior shoulder micro-instability should
be addressed adequately. Once the athlete has com-
pleted the progressive return to sport program with-
out complaint of pain or discomfort and has been
cleared by the surgeon, return to competitive activity
can be initiated.

Patients who are not athletes, should maintain the
flexibility, endurance and strength levels achieved
during Phase I-IV and may benefit from functional
progression programs for activities specific for their
function.

**CONCLUSIONS**

This clinical commentary provides an overview of
PASTA lesions, presents options for management
of these lesions, analyzes the common treatment approaches utilized to date, and describes a rehabilitation program based on available scientific evidence.

Post-surgical rehabilitation of PASTA lesions should consider surgical findings, patient age, level of activity, and patient-related outcome goals. Moreover, understanding of soft tissue healing timing is paramount as it affects rehabilitation choices and provides the basic foundation for the progression of a rehabilitation program.

Therapeutic modalities and rehabilitative exercises are often based on clinical experience rather than scientific evidence, therefore, future research on PASTA lesions should be focused on providing scientific rationale for the use of therapeutic modalities and exercise programs as well as timelines for progression.

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ABSTRACT

Background: The increasing number of athletes playing hockey compels rehabilitation professionals working in orthopedic and sports settings to understand the unique functional demands of ice hockey and the patterns of injuries they may promote.

Purpose: The purpose of this clinical perspective is to: (1) discuss the functional implications of different positions and age levels on injury prevalence within the sport; (2) summarize the seven most common injuries sustained by ice hockey athletes; and (3) present a conceptual model for the clinical management and prevention of these injuries by rehabilitation professionals.

Methods: A narrative review and synthesis was conducted of currently available literature on prevalence, etiology, rehabilitative intervention, prognosis, and prevention of ice hockey injuries.

Results: Research evidence is available to support the prevalence of injuries sustained while participating in ice hockey, as well as the most effective clinical treatment protocols to treat them. Most of the existing protocols are based on clinical and sports experience with incorporation of scientific data.

Conclusion: This clinical commentary reviews the current concepts of ice hockey injury care and prevention, based on scientific information regarding the incidence, mechanism, rehabilitation protocols, prognosis, and prevention of injuries. Science-based, patient-centered reasoning is integral to provide the highest quality of rehabilitative and preventative care for ice hockey athletes by physical therapists.

Key Words: Closed-head injuries, femoro-acetabular impingement, high ankle sprain injuries, ice hockey injuries, MCL injuries, shoulder injuries.

Level of Evidence: 5
INTRODUCTION

Ice hockey in the United States is an increasingly popular competitive sport, with participants ranging from youth players to professional athletes. Between 1990 and 2010, the number of athletes participating in all levels of ice hockey grew 143% in the United States. In 2013, 510,279 athletes were registered with USA Hockey, which is the national governing body for ice hockey athletes in the United States. Growing participation in ice hockey at all levels may lead to higher incidence of injuries sustained during practices and competitions than in the past. These injuries sustained on the ice, in turn, may increase the number of ice hockey injuries seen in general orthopedic and sports rehabilitation settings.

Ice hockey is unique in that it is a collision sport that requires participants to skate a narrow contact surface (blade) with a low friction surface (ice) while moving in all planes of motion. Injuries to the head, shoulder, hip, knee, and ankle and foot are most common, and their mechanisms of injury are unique to the sport. The increasing number of athletes playing hockey compels rehabilitation professionals working in orthopedic and sports settings to understand the unique functional demands of ice hockey and the patterns of injury they promote. Conceptual work that addresses the prevalence and mechanism of injuries specific to ice hockey is integral to providing the highest quality of care for hockey athletes. Further, rehabilitation protocols, prognosis and prevention of hockey injuries are essential pieces to provide uniform expectations regarding identification of at-risk but uninjured athletes, health/injury status, and anticipated return to play for injured athletes. The purpose of this clinical commentary are to: (1) discuss the functional implications of different positions and age levels on injury prevalence within the sport; (2) summarize the seven most common injuries sustained by ice hockey athletes; and (3) present a conceptual model for the clinical management and prevention of these injuries by rehabilitation professionals.

SPORT-SPECIFIC FUNCTIONAL REQUIREMENTS OF ICE HOCKEY

Ice hockey athletes have requirements for strength, speed, flexibility, and endurance that are unique to the sport and vary between positions. Three forwards, two defensemen, and one goaltender are on the ice at a given time for each team at full strength (not including shorthanded or powerplay scenarios); all of these positions have varying functional demands. For example, defensemen skate backward more often than they skate forward, and vice versa for forwards (Figure 1). However, both forwards and

Figure 1. Backward ice hockey skating. [Alternating legs backward stride. Offensive or defensive players will skate backwards during a game to play defense against an opposing team. A. left stance leg, right leg starting a “C” cut. B. left stance leg, right leg continuing “C” cut. C. left stance leg, right leg finishing “C” cut. D. right stance leg, left leg starting a “C” cut. E. right stance leg, left leg finishing a “C” cut back to starting position.]
defensemen are required to skate forward and crossover (Figure 2). These movement patterns predispose ice hockey athletes to various types of injuries. For example, skating backwards and forwards in the sagittal plane require completely different muscle contractions. The push-off stride in forward ice hockey skating requires hip extension, hip abduction, knee extension and ankle plantarflexion. The muscular contractions necessary to achieve this action include concentric hip extension, concentric hip abduction, concentric knee extension and concentric ankle plantarflexion. Additionally, isometric contractions of medial and lateral ankle stabilizers, and eccentric contraction of the hip adductors provide transference of force from the skate blade to the center of mass. The return to start motion requires hip flexion and adduction, knee flexion, and ankle dorsiflexion. Furthermore, stickhandling the puck to maintain possession requires hand-eye coordination, strength, endurance, and proprioception (Figure 3). Forwards are required to take face-offs after each stoppage of play, which call for flexibility, strength, stability, considerable balance, and proprioception (Figure 4). There are a variety of types of shots that can be taken during a hockey game, such as the wrist shot for accuracy (Figure 5), the
snap shot for quickness (Figure 6), and the slapshot for power and velocity (Figure 7). Goaltenders have periods of time with no action that can quickly change to periods of rapid-fire shots, requiring mental focus and quick reactions. Goaltenders must be flexible enough, especially in their lower extremities, to reach across the crease (goal mouth) to make a save if needed, while maintaining the strength and endurance to stay upright as long as shots are coming at them from the opposing team.

Recent evidence suggests important similarities between the strides of forward skating in ice hockey and speed-skating athletes. These similarities may have implications for sport-specific ice hockey training. Van Ingen et al describe the energy-system and power requirements for speed-skating athletes. For example, Van Ingen et al describes how speed skaters require a high breakdown rate of energy-rich phosphates in the first 4-5 seconds of the skating burst. This is imperative for ice hockey players as...
Players who effectively accelerate in the first few strides may have a higher percentage of winning the race to the puck and gaining puck possession, which is integral for a team’s success. The results of Van Ingren et al. suggest skaters improve their first push off by initiating a start technique that allows a more horizontally-directed propulsive force. This acceleration technique and explosive power for ice hockey athletes is key for their off-ice power training programs in order to initiate their stride at the highest velocity possible. Emphasizing a positive shin angle, which is when the knee is forward of the ankle, with skating form and utilizing harness resistance drills can be very beneficial approaches to improving acceleration. Rehabilitation professionals should utilize plyometric exercises that emphasize horizontally directed propulsive forces when athletes are towards the end of their rehabilitation stages and are preparing for return to participation. Plyometric and short-burst drills can improve the athlete’s acceleration and affect the rapid acceleration tasks required to win individual competitions for the puck throughout the course of a game.

**Epidemiology of Ice Hockey Injuries**

Ice hockey is a contact sport in which athletes may be at elevated risk for types of injury that require time away from practice and competitions. Engerbretsen et al. concluded that the risk of sustaining an injury was highest for ice hockey athletes compared to all registered athletes from other sports in the 2010 Olympics. According to Tuominen et al., the second period of games had the highest percentage of injury in players of any position, including forwards, defensemen, and goaltenders. These results indicate that proper endurance training of ice hockey athletes is imperative to not only improve their performance, but also reduce the risk of injury. Engerbretsen et al. also found that up to one-third of registered ice hockey participants sustained some type of injury during the study period that required time away from practice or competition. Engerbretsen et al. also found that ice hockey had the highest incidence of athlete-to-athlete trauma among all Olympic sports.

According to Agel et al., the percentage of injuries that occur during collegiate ice hockey games comprises 13.5% knee injuries, 8.9% acromioclavicular (AC) joint injuries, 6.2% upper leg contusions, and 4.5% pelvis and hip muscle strains. Emery et al. studied 986 minor hockey players, aged 9-17 years old. The authors of this study concluded that 45% of all injuries occurred during body checking, with concussions, shoulder sprain/dislocation, and knee sprain as the most common injuries.

The epidemiological analysis previously described will form the structure for conditions reviewed in this clinical commentary.

**Care and Management of Selected Ice Hockey Injuries**

The following sections of this clinical commentary will review the identification and rehabilitation
management of typical injuries sustained during hockey play. The injuries will include closed head injuries, injuries to the shoulder complex, hip, knee, and foot and ankle. The underlying sport-specific biomechanical predisposition for each injury will be discussed, along with unique rehabilitation considerations that relate to the functional requirements of the sport.

Closed head injuries
McCrory et al 9 defines concussion as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces. Clinically recognizable signs and symptoms of a concussion include headache, confusion, amnesia, dizziness, nausea, and fatigue. Deits and colleagues10 found the incidence of concussions is three-fold greater in ice hockey athletes aged 2-18 years (9%) compared to those older than 18 years (3%). These results may imply that novice and younger athletes are at elevated risk. It is notable that these estimates may be biased by several factors, including but not limited to competitive pressures, social perception, and team stigma that could promote under-reporting in older athletes. Johnson et al11 studied hockey players aged 16-21 years old and found that 17 of 67 (25.3%) sustained a concussion during a single season, with five of those players also suffering a second concussion. The results of this study indicated a rate of concussion seven times higher than the highest rate previously reported in literature. According to a prospective study performed by Echlin et al,12 8.47 in 1000 collegiate ice hockey athletes, including both men and women, sustained a concussion during a hockey season. Concussions at high levels of competition have important economic consequences. In the National Hockey League (NHL), 10% of concussions resulted in time loss of 10 days or greater, equating to roughly 11 games missed per occurrence.13 In the NHL, injuries represent a total salary cost of about $218 million dollars (USD) per year, with concussions making up about 20% of that total salary lost, accounting for 42.8 million USD.

The most common mechanism of injury for concussions in ice hockey is when the temporal side of the head is struck by another players’ body part or object.14 Wennberg et al15 concluded that the incidence of concussions in ice hockey is greater in forwards than defensemen and goaltenders. The authors of this review believe that a possible explanation for the increased risk for forwards is that these players commonly skate with the puck as compared to players in other positions, and therefore are more likely to be body-checked by an opposing player. In contrast, defenders commonly face the flow of play for the majority of action, while forwards spend a greater amount of time playing in a 360 degree field of play, moving forward to receive passes or crossing the ice in a lateral direction at high speed.

Optimal management of concussions in ice hockey athletes begins with accurate recognition and diagnosis, which can be complicated by symptom under-reporting by parents and athletes.16 Improved awareness of concussions needs to occur in all levels of hockey. Rehabilitation professionals’ outreach activities should be oriented toward the youth ice hockey population, which is the largest and also most at risk for concussions.10 Appropriate recognition and management of concussions needs to be explained to younger athletes and those around them to ensure their safety as the number one priority. Epidemiological studies of concussions in ice hockey have incorporated the use of formal pre-participation baseline cognitive and psychomotor testing, such as the Sport Concussion Assessment Tool 2 (SCAT2) and Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) in order to determine a baseline for each athlete and aid in the diagnosis of a concussion when a closed head injury is sustained.16 Szabo et al concluded that there is a need for further information about the ImPACT validity indices and whether they truly reflect poor effort, or if there is a learning effect present.17 The authors of this commentary suggest that pre-participation screening should occur at all competitive levels of ice hockey.

Treatment protocols for concussions vary in different organizations; so average time out of the game for concussion may vary greatly between skill levels and age groups for both patient-specific and protocol-specific reasons. The return to play timeline is and needs to be longer for youth athletes after sustaining mTBI. The National Hockey League requires a five step return-to-play protocol in order for an athlete to return to full participation after...
sustaining a concussion (Table 1). This system is controversial, however, with the early days of the protocol including full physical and cognitive rest. It has been suggested that active rest/reduced cognitive and physical activity may be better. Alsalaheen and colleagues studied the effectiveness of vestibular rehabilitation to reduce dizziness and improve gait and balance in a number of athletes, including ice hockey participants, who had sustained a concussion. In this study, the role of vestibular rehabilitation is emphasized to ensure player is safe with regard to gaze stabilization prior to return to play. The authors of this study concluded that vestibular rehabilitation should be considered in management of individuals post-concussion who experience dizziness and that are not resolved with rest. Further research should be conducted in the area of physical therapy management of closed head injuries to examine the role of the physical therapist, including but not limited to: graded exercise therapy and monitoring of symptoms with aerobic activity.

**Table 1. Gradual return-to-play protocol after a concussion.**

<table>
<thead>
<tr>
<th>Rehabilitation Stage</th>
<th>Function Exercise at Each Stage</th>
<th>Objectives of Each Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No activity</td>
<td>Symptom-limited physical and cognitive rest</td>
<td>Recovery of injured brain</td>
</tr>
<tr>
<td>2. Light aerobic exercise</td>
<td>Walking, swimming, or stationary cycle, keeping intensity &lt;70% of maximum permitted heart rate; no resistance training</td>
<td>Increase heart rate, without increased symptoms</td>
</tr>
<tr>
<td>3. Sport-specific training</td>
<td>Skating drills for ice hockey, no head-impact activities</td>
<td>Add movement</td>
</tr>
<tr>
<td>4. Non-contact training drills</td>
<td>Progression to more complex training drills, for example, passing drills in ice hockey; may start progressive resistance training</td>
<td>Exercise, coordination and cognitive load</td>
</tr>
<tr>
<td>5. Full contact practice</td>
<td>After medical clearance, participation in normal training activities</td>
<td>Restore confidence and assessment of functional skills by coaching staff</td>
</tr>
<tr>
<td>6. Return to play</td>
<td>Normal game play</td>
<td>Discharge</td>
</tr>
</tbody>
</table>

Shoulder complex injuries
Shoulder complex injuries – consisting of those that occur at glenohumeral joint, acromioclavicular joint, and corresponding soft tissue structures – make up 18% of all ice hockey injuries. Approximately three-quarters of shoulder complex injuries result from contact with another athlete, most commonly as a result of body-checking. According to Donaldson et al., shoulder injuries account for a total of $306,600 USD in salary loss per season in the NHL. The growing prevalence of contact with body checking at younger ages in ice hockey increases the athletes’ risk of sustaining a shoulder injury.

**Glenohumeral joint injuries**
Glenohumeral joint (GHJ) subluxation and dislocation occurs in approximately 8% of elite Swedish ice hockey athletes, aged 18-26. Anterior dislocations and subluxations occur most often when the shoulder is forced posteriorly from contact with another player or a directly blow to a shoulder that is abducted and externally rotated, causing anterior displacement. An injury to the GHJ could occur to any forward, defenseman, or goaltender who may come into contact with another player. The presence of GHJ subluxation or dislocation may be confirmed the external rotation apprehension special test. The prognosis for return to play from glenohumeral joint injury depends on the severity of the
damage to the supporting structures of the GHJ. Skating is often contraindicated with GHJ injuries until near end phase of rehabilitation due to the possibility of unanticipated falls. Dryland training is an ideal alternative, where a rehabilitation professional may be of high priority. Rehab professionals should utilize high level therapeutic exercise to improve strength, power, and endurance. Sport-specific exercises to include stick handling, shooting, and skating may be instrumental in progressing the athlete back to their sport as quickly as possible.

**Acromioclavicular joint injuries**

Another shoulder pathology that is common among hockey athletes is acromioclavicular joint (ACJ) sprain. ACJ injuries commonly occur when an individual lands directly on the ACJ or when the athletes’ shoulder is checked shoulder-first into the boards. An important prevention strategy that can be used to help with prevention and return-to-play treatment of ACJ injuries is the use of a protective foam pad used under the athlete's shoulder pads to attenuate impact and protect the injured ACJ in the event of another body check mechanism. ACJ conditions can be ruled out or confirmed with clinical special tests, such as the ACJ compression and crossover tests. The Bell van-Riet test consists of cross-body adduction by the patient as well as attempted elevation against resistance (SN 98%) and can be used as a clinical special test when ACJ involvement is suspected.22

**Prevention of shoulder complex injuries**

Sprague and colleagues23 found that the Functional Movement Screen (FMS™) shoulder mobility test can be used to supplement shoulder range of motion, thoracic spine mobility, motor control, soft tissue mobility, and muscle imbalance assessments as a more comprehensive screening tool for injury prevention measures. Global shoulder and rotator cuff strengthening programs should be implemented in all training programs for ice hockey participants as a pre-habilitation technique in order to decrease the prevalence of shoulder complex injuries.24 Findings from the shoulder mobility section of the FMS™ can provide rehabilitation professionals with a more specific route than isolated muscle strength and range of motion testing from which to direct the rest of their examination. This allows the rest of the examination and evaluation to be more specific when performing range of motion and strength assessments, as well as any special tests. During pre-participation physicals, rehabilitation professionals should include functional screening tools, range of motion and strength testing, and obtain a detailed medical history of any previous shoulder problems in order to note athletes who may be at elevated risk for sustaining a shoulder complex injury.

**Hip injuries**

The hip, thigh, and groin is the location of approximately 10% of all ice hockey injuries.8 Femoroacetabular impingement (FAI) and adductor strains are two of the most common health conditions in ice hockey athletes that involve this joint.9

**Femoroacetabular impingement**

FAI is most common in goaltenders, especially those who play the “butterfly-style” position as they are constantly moving into and out of position of hip flexion and internal rotation (Figure 8). Philippon et al observed 28 ice hockey players who received hip arthroscopy on one hip to treat FAI and labral damage.25 Participant age ranged from 18-36 years old, with all radiographs showing evidence of cam impingement, and 85% of the images showing mixed cam and pincer impingement.25 The authors of this study concluded that professional ice hockey players with FAI can return post-operatively to skating and their prior level of participation at the professional level. Further, the study highlighted the importance
of early recognition of the signs and symptoms of FAI by the athletes and health care professionals. It is imperative to do so in order to seek treatment as early as possible, in order optimize prognosis. Special tests that can be used to confirm the presence of FAI include the flexion-abduction-external rotation (FABER) and flexion-adduction-internal rotation (FADIR) tests. According a study performed by Phillippon et al, the sensitivity of the FABER test is .71 with a specificity of 1.0 and found that 97% of patients with labral impingement were (+) on the test.26

Pierce et al27 described a functional post-surgical rehabilitation program for FAI in ice hockey goaltenders that could also be applied to other on-ice positions. The protocol suggests on-ice return to sport-specific drills four months post-operatively, with a return to competition shortly thereafter.27 The program is divided into a four-phase rehabilitation protocol plus six phases of on-ice training (Table 2). Return to participation is determined when the injured athlete obtains successful pass of a score higher than 17/20 on the Vail Hip Sports Test without reported increase

| Table 2. Phases and timelines for the standard rehabilitation protocol following arthroscopic hip surgery without microfracture for FAI and labral tears, and the one-ice supplemental rehabilitation program designed for ice hockey goaltenders.25 |
|-----------------|-----------------|-----------------|-----------------|
| Rehabilitation Phase | Goals | Precautions/Restrictions | Treatment Strategies |
| Phase 1 (Weeks 1-10) | 1. Protection  
2. Decrease inflammation  
3. Early ROM  
4. Prevent muscle inhibition  
5. Education | 1. Limit external rotation and extension  
2. Weight-bearing restrictions for 4 weeks | 1. Continuous passive motion  
2. Stationary bike  
3. Circumduction  
4. Massage  
5. Isometrics  
6. Pool therapy  
7. Ice |
| Phase 2 (Weeks 4-12) | 1. Normalize gait  
2. Restore full ROM  
3. Neuromuscular control | 1. Avoid muscle irritation, especially hip flexors  
2. Avoid overloading the joint | 1. Wean from crutches  
2. Weight bearing stability exercises |
| On-Ice Phase 1 (Week 4) | 1. Normalize skating | | |
| On-Ice Phase 2 (Week 5) | 1. Normalize skating with pads | | |
| On-Ice Phase 3 (Weeks 7-10) | 1. Light goalie-specific movements | | |
| On-Ice Phase 4 (Weeks 10-12) | 1. Crease work without butterfly (speed) | | |
| On-Ice Phase 5 (Week 13-on) | 1. Crease work with butterfly (explosive movements) | | |
| Phase 3 (Weeks 5-13) | 1. Restore endurance strength  
2. Optimize neuromuscular control  
3. Restore cardiovascular fitness | 1. Overloading the joint | 1. Double- to single-leg strength  
**Pass Vail Hip Sports Test** |
| Phase 4 (Weeks 13-on) | 1. Restore power and strength  
2. Return to play | | 1. Power and conditioning |
Adductor muscle strains

Adductor strains are common in ice hockey players because of the unique skating stride that occurs while playing and training. Chaudhari and colleagues describe that large, eccentric contractions of the adductor muscle group are known to result in or exacerbate adductor strain injuries. Therefore, the constant eccentric and concentric loading of the adductor muscle group during a forward skating stride lead to strain on the contractile tissue, which may lead to injury. Clinical evaluation and examination should include the hip adductor group manual muscle testing, as well as alignment checks of the pelvis and sacrum. The prognosis for adductor strains depends heavily on the patient's previous injury history as well as the severity of the muscle strain/tear. Intervention for hip adductor muscle strains should begin with restoring hip mobility and soft tissue extensibility. Hip muscle and thoraco-lumbo-pelvic complex strengthening should accompany acute phase interventions for adductor strains, including adaptation to a player's stride by improving hip abductor and external rotator activation. Improving deep core stabilization, which includes activation of the transversus abdominus and the pelvic floor musculature, can help distribute the mechanical stresses placed on the adductor muscles during a stride. Hip and lumbopelvic motor control development also plays a key role in rehabilitation of adductor muscle strains. Not only do ice hockey athletes need femur-on-acetabular range of motion and control, but they also need proper neuromuscular control of closed-chain acetabular-on-femur motion at the hip joint. For example, improved strength, range of motion, and motor control available for a particular athlete after going through rehabilitation for an adductor strain could provide a more mechanically advantageous stride that may offload injured tissues.

Knee injuries

Fifteen percent of all ice hockey injuries in minor hockey occur at the knee joint, with medial collateral ligament (MCL) sprains accounting for 44 per 10,000 ice hockey athlete-hours. The high incidence of this injury largely is due to the on-ice collisions that produce excessive valgus force at the knee. Forwards are most likely to sustain this injury, since they are typically skating forward and can be body checked below their center of mass, creating a valgus load at the knee and injuring the medial knee structures. The MCL valgus stress test is a special test that should be utilized to confirm or rule out an MCL sprain in the clinic. Aronson et al found that the tibiofemoral joint should be fully extended or flexed to 5 degrees to assess all resisting medial tibiofemoral joint structures (including the anterior cruciate ligament) and again at 15 to 20 degrees of flexion to further assess the MCL. The prognosis for returning to competition from isolated MCL injuries depends heavily on the athlete's adherence to his or her rehabilitation protocol and the severity of the injury. The participant can usually return between zero and two
weeks after a Grade I injury and between two to four weeks after a Grade II injury.\textsuperscript{32} The prognosis for a Grade III MCL injury is generally six to eight weeks before return to full ice hockey competition. Appropriate rehabilitation of the MCL after injury is essential to restore the ability to tolerate the push-off and cross over motions required during skating.

A well-guided treatment program is essential following MCL injury. Acute phase interventions are important following injury, with compression particularly effective to decrease knee edema.\textsuperscript{32} Rehabilitation for MCL injuries should place emphasis upon open chain progressing to closed chain hip abductor strengthening starting in the sagittal plane and progressing to the other planes of motion, in order to decrease the risk of valgus load being placed on the knee joint. Improvements of lateral hip rotation range of motion decreases valgus knee stresses with load and should be included in any rehabilitation program to the MCL. Active knee range of motion exercises, including cycling and active range of motion, can prevent loss of range of motion that may occur from disuse. Following MCL injury, ice hockey athletes should maintain year-round quadriceps and hamstring strengthening and continued hip, oblique, and core strengthening exercises in order to decrease the amount of time lost and decrease the risk of re-injury. Marchant et al suggests using an unlocked hinged knee brace during the early stages of treatment and during return to sport, and discontinue its use after the competitive season is over.\textsuperscript{32} Athletes who sustain a severe MCL tear (i.e. isolated Grade III injuries) may require reconstructive surgery. Effective skating at a competitive level is impractical if not impossible without an MCL to stabilize the medial knee during the skating motion. Chronic valgus instability or rotatory instability are two of the most important issues that need to be addressed when it comes post-reconstructive treatment interventions.\textsuperscript{32} These instabilities should also be checked at pre-operative initial evaluation in order to maximize rehabilitation efforts. Exercises to improve lower extremity proprioception, hip, trunk, and pelvis stability and neuromuscular control, and knee motor function are key to an athlete's prognosis to return to play following reconstructive surgery of the MCL.

An important aspect of MCL injuries sustained by ice hockey athletes is the prevention of these injuries from occurring. Pre-season functional screens, including single-leg stance and squat screen, hip mobility and pelvic alignment assessments, muscle-length testing such as the Thomas and Ober's tests, and postural analysis should be performed by healthcare professionals to note which players may be more susceptible to an injury to the MCL.\textsuperscript{33} Rehabilitation professionals should observe for and address any increased valgus loading during a squat or static genu valgum which may put stress on the MCL without an external force being applied. The Landing Error Scoring System can be used as a screening tool to detect valgus along with single limb drop landings.\textsuperscript{32} Best clinical practices should encompass pre-season assessments, as well as monthly in-season and post-season monitoring to address the functional demands of the ice hockey participants and work to decrease risk of MCL injury.

**Figure 9. Hockey skate photo.** Typical ice hockey skate worn on the right foot shows that it covers approximately \(\frac{1}{4}\) of the lower leg.

**Foot and ankle injuries**

Lower leg injuries are relatively infrequent in ice hockey, accounting for only about 6\% of injuries.\textsuperscript{8} Ice hockey players wear skates that encase the entire foot and ankle complex; the typical ice hockey skate runs approximately one quarter of the way up the lower leg, which provides more lateral foot and ankle stability seen during other cutting and collision sports (Figure 9). Thus, lateral ankle
sprains associated with an inversion mechanism are far less common in ice hockey players than high ankle sprains. Conversely, non-goalie skates position the ankle in a 5-10 degree dorsiflexed position in order to aid in the skating stride by holding the center of mass forward. As high ankle sprains occur with forced dorsiflexion and eversion, the position of the skate along increases the risk for this type of injury. The most common injury to the lower leg sustained by ice hockey athletes involves the distal tibiofibular syndesmotic complex (i.e. “high ankle sprain”). Syndesmotic injuries occur when the talus is forced into excessive abduction with the talocrural joint positioned in extreme dorsiflexion, in the man-

<table>
<thead>
<tr>
<th>Rehabilitation Stage</th>
<th>Goals</th>
<th>Sample Treatments</th>
<th>Criteria for Progression</th>
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</table>
| **Acute**            | Joint protection while minimizing pain, inflammation, weakness, and loss of motion | 1. *Joint protection*: immobilization in a walking cast, boost, custom orthosis, lace-up ankle brace, or ankle stirrup. External rotation and end range dorsiflexion are avoided.  
2. *Weightbearing*: based on assessment and patient symptoms – varies from non-weightbearing to full weightbearing.  
3. *Pain and inflammation control*: compression, elevation, cryotherapy, electrical stimulation, manual therapy, other modalities, and/or alternative therapies such as acupuncture.  
4. *Maintenance of strength and mobility*: gentle motion, cycle ergometer, progressive resistance exercise with bands, cords, ankle weights, and/or electrical stimulation. | Able to ambulate in full weightbearing on various surfaces and traverse stairs with minimal discomfort. |
| **Subacute**         | Normalize joint mobility, strength, neuromuscular control, and return to basic function in activities of daily living | 1. *Mobility*: low-load, long-duration stretching with cords, bands, or towels; repetitive motion through the range of motion; cycle ergometer; joint mobilization; and/or aquatic therapy.  
2. *Strengthening*: cords, bands, ankle weights, heel raises, step up/down, calf press with isotonic equipment, and/or neuromuscular training exercises.  
3. *Neuromuscular training*: progressive use of air cushions, rocker boards, wobble boards, air-filled domes, trampolines, or other perturbation of support surfaces. | Can jog and hop with minimal discomfort. |
| **Advanced Training**| Prepare for return to sports participation | 1. *Neuromuscular training*: perturbation of support surfaces.  
2. *Functional/agility drills*: running, jumping rope, hopping, shuffling, carioca, and/or figure-8 running with or without use of props such as cones, hurdles, and ladders.  
Clinical tests that may be used to rule out or confirm a high ankle sprain include direct palpation to the site of injury, the tibiofibular squeeze test, external rotation stress or Kleiger's test, and the fibula translation test. If a high ankle sprain is suspected, plain film radiographs should be taken if possible to rule out lower leg and foot fractures, which can present with similar symptoms.

The prognosis for high ankle sprains in ice hockey athletes is difficult to predict due to the nature of the sport. According to Laprade et al, syndesmotic injuries could take up to 12 weeks to heal in ice hockey athletes. Williams et al advocates a three-stage rehabilitation approach for tibiofibular syndesmotic injuries (Table 3). The acute phase includes immobilization, protected weight bearing, and control of the inflammatory. The sub-acute phase is related to healing, and the goals are to regain normal foot and rearfoot mobility, and introduce strengthening and neuromuscular control activities. The third and final stage involves advanced training and game-like situations on the ice. More aggressive training exercises and hockey-specific activities should be implemented in this stage to get the player ready for game speed. Returning to play after sustaining a syndesmotic injury should only occur when appropriate proprioception, or recognition of joint location in space, as well as neuromuscular control of the foot in all three planes of motion are demonstrated by the athlete during both advanced training exercises and on the ice.

CONCLUSION
This clinical commentary provided an overview of the seven most common injuries sustained by ice hockey athletes along with current, evidence-based treatment protocols for healthcare professionals to utilize when they work with one of these patients. Sport-specific injuries such as concussions, glenohumeral dislocations, acromioclavicular joint separations, FAI, adductor strains, MCL sprains, and syndesmotic injuries can be treated non-operatively and rehabilitation professionals should utilize their clinical skills and reasoning to properly address and rehabilitate these athletes back to their prior level of function, when appropriate. It is imperative for the rehabilitation professional to recognize, treat, and refer injuries based on a sound understanding of the unique functional requirements of the sport and its widening popularity. Further research should be performed to examine the most effective treatment protocols to provide the highest quality of care to these athletes and pre-season assessment tools to attempt prevention strategies.

REFERENCES


