ABSTRACT

Objectives: To evaluate intra-rater and inter-rater reliability and measurement error in glenohumeral range of motion (ROM) measurements using a standard goniometer.

Study design: 17 adult subjects with and without shoulder pathology were evaluated for active and passive range of motion. Fifteen shoulder motions were assessed by two raters to determine reliability. The intra-class correlation coefficients (ICC) were calculated and examined to determine if reliability of ICC ≥ 0.70 existed. The standard error of measurement (SEM) and the minimal clinical difference (MCD) were also calculated.

Results: The criterion reliability was achieved in both groups for intra-rater reliability of standing AROM abduction; supine AROM and PROM abduction, flexion, external rotation at 0° abduction; and for inter-rater reliability of supine AROM and PROM abduction, external rotation at 0° abduction. The SEM ranged from 4°-7° for intra-rater and 6°-9° for inter-rater agreement on movements that achieved the criterion reliability. The MCD ranged from 11°-16° for a single evaluator and 14°-24° for two evaluators.

Conclusions: Assessment of AROM and PROM in supine achieves superior reliability. The use of either a single or multiple raters affects the number of movements that achieved clinically meaningful reliability. Some movements consistently did not achieve the criterion and may not be the best movements to monitor treatment outcome.

Key Words: Reliability, shoulder goniometric measurement

CORRESPONDENCE

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INTRODUCTION

Clinicians and researchers routinely evaluate change in patients’ status over time. The assessment of range of motion (ROM) is important in the 1) diagnosis of glenohumeral disorders, 2) evaluation of treatment progression and effectiveness, and 3) quantifying the amount of change in movement that occurs. It is, therefore, important for clinicians and researchers to have complete and relevant information on the reliability and accuracy of ROM measurement.

Common scenarios that arise in daily clinical practice highlight the need to reliably determine ‘real’ change in a patient’s condition. Clinicians want to know how to determine patients’ progress over time with the same clinician performing assessments or how to relate measurements between clinicians when patient care is transferred from one person to another. These same issues also impact clinical research from both a research design and data analysis perspective particularly when multiple evaluators are used to evaluate progress over time.

Clinical assessment of the extremities usually involves obtaining information on an affected and an unaffected side for comparison. The presence of glenohumeral pathology can contribute to variation in measurement due to pain, weakness, fatigue and apprehension in addition to the variation in performing the measurement technique alone. Thus, it is important to ensure that measurements used in a clinical setting are reliable in both the presence and absence of shoulder pathology.

The intra-class correlation coefficient (ICC) quantifies reliability or consistency in a measurement; the closer the value is to 1.0, the better the reliability. However, the ICC value does not provide a quantification of the magnitude of the error. Evaluating the smallest detectable change has also been advocated as an important aspect of a reliability study. The standard error of measurement (SEM) expresses agreement in the same units as the original measurement and indicates the amount of change needed to exceed the error of the measurement itself. Knowledge of the error in the measurement technique allows for the determination of when an observed change equates to a minimum detectable change that is greater than measurement error itself.

Wide variability for both intra and inter-rater reliability for shoulder motion evaluation has previously been reported. Limitations in the previous literature that have reported the accuracy of assessing shoulder range of motion with a goniometer should be considered as important omissions. Specifically, these limitations include presentation of estimates without confidence intervals, inadequately powered sample sizes, no sample size calculations, failure to present SEM values and a limited number of possible shoulder movements assessed. (Table 1)

There is a threshold below which the consistency and precision of a measure is considered compromised and ceases to be clinically useful and informative. It is recommended that ICC values be greater than or equal to 0.70 to be considered acceptable as a clinically meaningful measurement tool. In the shoulder reliability literature, this form of statistical analysis has not been previously performed, thus we do not know if goniometric assessment of glenohumeral ROM meets an acceptable standard.

The purpose of this study was to calculate 1) intra and inter-rater reliability ICC values for shoulder range of motion, 2) intra and inter-rater standard error of measurement (SEM) for each movement and 3) the minimal clinical difference (MCD) in a group of people with and without shoulder pathology for each movement assessed by a single evaluator and two evaluators.

MATERIALS AND METHODS

Subjects

A convenience sample of subjects with and without shoulder pathology was recruited from staff and patients attending the outpatient Department of Rehabilitation Medicine at Grey Nuns Community Hospital, Edmonton, Alberta. The study was approved by the University of Alberta Health Research Ethics Board (Biomedical Panel) and Caritas Research Steering Committee, Edmonton, Alberta and informed consent was obtained from all participants.

People were eligible for the study if they were between 18 and 75 years of age, able to easily move between supine and standing positions, and able to actively move their shoulder into 90° of glenohumeral abduction. Exclusion criteria for both groups
<table>
<thead>
<tr>
<th>Author</th>
<th>Sample size (N), Number of assessors (n)</th>
<th>Study Sample</th>
<th>Measurement</th>
<th>Movements</th>
<th>ICC values</th>
<th>Limits of Agreement</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riddle et al 1987&lt;sup&gt;2&lt;/sup&gt;</td>
<td>N=100 (two groups of 50) n=16</td>
<td>Pathology</td>
<td>PROM</td>
<td>Intra-rater reliability: F E Abd H Abd H Add ER &lt;br&gt; Inter-rater reliability: F E Abd H Abd H Add ER</td>
<td>Point estimates only</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Bovens et al 1990&lt;sup&gt;5&lt;/sup&gt;</td>
<td>N=8 n=3</td>
<td>Normal</td>
<td>PROM</td>
<td>Intra-rater reliability: ER &lt;br&gt; Inter-rater reliability: ER</td>
<td>Point estimates only</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Sabari et al 1998&lt;sup&gt;11&lt;/sup&gt;</td>
<td>N=30 n=1</td>
<td>Normal and pathology</td>
<td>PROM and AROM - supine and sitting</td>
<td>Intra-rater reliability: F Abd</td>
<td>Point estimates only</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>MacDermid et al 1999&lt;sup&gt;10&lt;/sup&gt;</td>
<td>N=34 n=2</td>
<td>Pathology</td>
<td>PROM</td>
<td>Intra-rater reliability: IR &lt;br&gt; Inter-rater reliability: IR</td>
<td>Point estimates with 95% confidence intervals</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Hayes et al 2001&lt;sup&gt;8&lt;/sup&gt;</td>
<td>Inter-rater: N=8 n=4&lt;br&gt;Intra-rater: N=9 n=1</td>
<td>Pathology</td>
<td>AROM</td>
<td>Intra-rater reliability: F Abd ER &lt;br&gt; Inter-rater reliability: F Abd ER</td>
<td>Point estimates with 95% confidence intervals</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Nadeau et al 2007&lt;sup&gt;6&lt;/sup&gt;</td>
<td>N=30 n=2</td>
<td>Normal and pathology</td>
<td>AROM</td>
<td>Intra-rater reliability: EL RET PRO &lt;br&gt; Inter-rater reliability: EL RET PRO</td>
<td>Point estimates only</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

F=flexion, E=extension, Abd= abduction, H Abd=horizontal abduction, H Add=horizontal adduction, ER=external rotation, IR=internal rotation, EL=elevation, RET=retraction, PRO=protraction
were acute pain/injury of either shoulder, previous fracture of the scapula or proximal humerus, active joint or systemic infection, neurological conditions (e.g. stroke, Parkinson's Disease, brachial plexus injury, etc), significant muscle paralysis of the rotator cuff, deltoid or shoulder girdle musculature, inability to speak or read English, psychiatric illness that precluded providing informed consent or the ability to consistently perform the testing protocol. The self-report of no previous or current shoulder problems placed the participant in the without shoulder pathology group. The shoulder pathology group included participants who reported chronic and stable musculoskeletal injuries of the shoulder.

A sample size for ICC parameter estimation was based on an α value of 0.05, a β value of 0.20, an expected ICC value (intra and inter-rater reliability) of 0.90 with the minimum value in the one-sided 95% confidence interval of 0.70, using 2 replicates of each measurement and 2 evaluators. Using these parameters and defining the unit of assessment being a shoulder, the estimated sample size required 19 shoulders to be assessed in each group.

The evaluators were two registered physical therapists with 16 and 12 years of experience in the assessment and treatment of orthopedic conditions, and as evaluators in orthopedic surgical trials of shoulder conditions. A study assistant was used for the recording of the measurement data during the test sessions. Data collection began in January 2005 and ended April 2005.

**Design**
The evaluators and study assistant participated in a one-hour formal training session. Study participants performed a set of warm-up exercises to reduce the risk of a mobilization effect from the repeated movements performed during the assessment. The warm-up routine included 10 repetitions of each exercise of shoulder pendular exercises, and active assisted shoulder extension, flexion, internal and external rotation exercises in standing.

Fifteen movements were assessed; four active range of motion (AROM) movements in standing and eleven movements of both AROM and passive range of motion (PROM), in supine, see Table 2. Scapular stabilization was used during the evaluation of internal rotation and horizontal adduction in supine. Details of the test positions, manual stabilization and goniometer placement are found in Appendix 1.

Each participant presented on one occasion for approximately one hour and was assessed successively by the two evaluators. A single shoulder was considered the unit of study. Each evaluator independently measured one or both shoulders of each participant twice during the test session, providing a total of four ROM assessments per study shoulder. The evaluator order, the order of the shoulder to be assessed first, the two assessment positions (supine and standing), and the order of the movements in each position were randomly assigned for each participant at the start of the test session by the study assistant.

To prevent measurement bias, the goniometer dial was covered with white paper, as described by Riddle et al. This method obscured the numerical values on the goniometer to the evaluators, but allowed the study assistant to view the reverse side of the goniometer to record the values. The recorded values of test measurements were not made available to the evaluators until study recruitment was completed and the last test session was finished.

**Joint Measurements**
All goniometer measurements were maximal joint motions measured with the JAMAR E-Z Read goniometer, a standard 12 inch, double-armed 360° goniometer, constructed of clear plastic. For testing, the subject was placed in the appropriate starting position, which was with the arm by the side, except where specified otherwise. Goniometer placement was done after the movement was performed and maximal range of motion achieved. Active range of motion was determined by the participant's self-report of reaching maximal amount of motion, while passive range of motion was determined by the assessing physiotherapist's report of reaching maximal passive end feel. No participants were limited by pain in either active or passive range of motion.

**Data Analysis**
The following analyses were performed for the normal and pathological groups separately.
Comparisons were made between these analyses of the number and type of movements that achieved the criterion level of reliability. The intra and inter-rater ICC values were calculated by performing two-way analysis of variance (ANOVA) for each movement using the random effects statistical methodology described by Eliasziw et al.\textsuperscript{14} Point estimates and 95% one-sided lower-limit confidence intervals for the ICC values were calculated. In this study, an ICC value with a confidence interval that had a lower limit greater than or equal to 0.70 would indicate that it achieved the criterion level of reliability deemed necessary for clinical utility. A lower confidence interval bound of below 0.70 would indicate the measure did not achieve the criterion level, regardless of the point estimate value.

The calculation of intra-rater and inter-rater reliability ICC values and standard error of the measurement were performed using the approach described by Eliasziw et al.\textsuperscript{14} instead of conventional calculations used to determine SEM. Data analyses were

<table>
<thead>
<tr>
<th>Test Position</th>
<th>Type of Movement</th>
<th>Specific Movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing</td>
<td>AROM</td>
<td>Abduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extension</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flexion</td>
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<tr>
<td></td>
<td></td>
<td>Scaption</td>
</tr>
<tr>
<td>Supine</td>
<td>AROM</td>
<td>Abduction</td>
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<tr>
<td></td>
<td></td>
<td>Flexion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ER at 0° abduction</td>
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<tr>
<td></td>
<td></td>
<td>ER at 90° abduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IR at 90° abduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Horizontal adduction</td>
</tr>
<tr>
<td>Supine</td>
<td>PROM</td>
<td>Abduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flexion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ER at 0° abduction</td>
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<tr>
<td></td>
<td></td>
<td>ER at 90° abduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Horizontal adduction</td>
</tr>
</tbody>
</table>

Table 2. Shoulder Movements Assessed in Study.

Abbreviations: AROM, active range of motion; PROM, passive range of motion; ER, external rotation; IR, internal rotation.

RESULTS
Data from 17 individuals, representing 23 normal shoulders and 11 abnormal shoulders were collected. The average age of subjects in the sample was 45.1 years (range 23-83 years) and there were 14 females and 3 males. The pathologies of study shoulders included: osteoarthritis (1), history of strain with ongoing symptoms due to a motor vehicle accident (1), rotator cuff tendinopathy (5), distal humerus fracture (1), dislocation (1) and instability without history of dislocation (2).

The movements that achieved the criterion level of reliability in the normal and pathology groups had similar point estimates and 95% confidence intervals, SEM, and MCD.

As expected, intra-rater reliability values achieved more criterion levels of reliability than inter-rater values for both PROM and AROM movements in standing and supine for both normal and pathological shoulders, demonstrating that there was less variability when the same evaluator was used (Tables 3 and 4). The values for standing AROM scaption, (See Appendix 1 for definition/description), and supine AROM horizontal adduction did not meet the criterion level in the pathology group and may be a result of low power in this sample. The intra-rater reliability values for standing AROM abduction; supine AROM abduction, flexion, and external rotation (ER) at 0° abduction; and supine PROM abduction, flexion and ER at 0° abduction met or surpassed the pre-specified criterion value in both groups.

Inter-rater reliability values were typically of lower magnitude than intra-rater reliability indicating greater variation, as expected, when two evaluators were used in both the normal and pathology groups. The inter-rater reliability values of 4 movements; supine AROM and PROM of abduction and external rotation at 0° abduction met the criterion for reliability in both groups, suggesting that these movements can be reliably measured and provide clinically useful information.

Importantly, there are movements that consistently did not achieve the criterion value in either group.

The intra-rater reliability measure for standing AROM extension did not achieve the criterion. Several additional movements failed to achieve the criterion value for inter-rater reliability including standing AROM abduction, flexion, and extension; supine AROM internal rotation, horizontal adduction; and supine PROM horizontal adduction.

Both the SEM and the MCD values for intra-rater agreement were smaller than for inter-rater agreement consistent with less measurement variation that is typical when the same evaluator is used. (Tables 3 and 4) Movements that met the criterion level had comparable values in both the normal and pathology group. However, large values were still present for some movements that achieved the criterion value for reliability; in particular supine AROM abduction had a MCD for two raters of 20° in normal shoulders and 24° in pathologic shoulders.

DISCUSSION
This study gives a comprehensive presentation of reliability and minimal clinical difference (MCD) values for 15 movements of the shoulder commonly used in clinical practice and research. The results provide valuable information on the limits of assessment for reliability and enables clinicians to make knowledgeable decisions regarding whether a clinically meaningful change has occurred between testing sessions, or whether the change could primarily be due to variability from measurement error.

This evaluation of shoulder range of motion reliability includes the largest selection of movements compared to previous reports and addresses the limitations present in the current published literature on goniometric measurement. While the authors acknowledge the importance of assessing glenohumeral rotations in 90° abduction, they were only assessed during active movement in supine in the current study. Performance of these movements in standing presents measurement challenges of isolating glenohumeral range from movement due to scapular movement and associated thoracic spine motions of rotation and extension that accompany the glenohumeral movements associated with throwing. Awan et al evaluated three techniques for measuring shoulder internal rotation using an inclinometer and reported that the use of scapular
### Table 3. Reliability with One-sided 95% Confidence Intervals, Standard Error of the Measurement (SEM) and Minimum Clinical Difference (MCD) Values are shown for a single rater and two raters when examining patients with normal shoulders. (N = 23)

<table>
<thead>
<tr>
<th>Movement</th>
<th>Average Range of Motion (SD)</th>
<th>Intra-rater reliability</th>
<th>Intra-rater SEM</th>
<th>MCD for single rater</th>
<th>Inter-rater Reliability</th>
<th>Inter-rater SEM</th>
<th>MCD for two raters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standing AROM:</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Abduction</td>
<td>170 (14)</td>
<td>0.91 (0.82, 1)*</td>
<td>4</td>
<td>11</td>
<td>0.67 (0.53, 1)</td>
<td>8</td>
<td>22</td>
</tr>
<tr>
<td>Extension</td>
<td>53 (8)</td>
<td>0.76 (0.58, 1)</td>
<td>4</td>
<td>11</td>
<td>0.77 (0.66, 1)</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Flexion</td>
<td>160 (12)</td>
<td>0.86 (0.74, 1)*</td>
<td>5</td>
<td>12</td>
<td>0.76 (0.65, 1)</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>Scaption</td>
<td>169 (12)</td>
<td>0.91 (0.83, 1)*</td>
<td>4</td>
<td>10</td>
<td>0.82 (0.74, 1)*</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td><strong>Supine AROM:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abduction</td>
<td>167 (16)</td>
<td>0.87 (0.76, 1)*</td>
<td>6</td>
<td>16</td>
<td>0.80 (0.70, 1)*</td>
<td>7</td>
<td>20</td>
</tr>
<tr>
<td>Flexion</td>
<td>170 (8)</td>
<td>0.92 (0.83, 1)*</td>
<td>2</td>
<td>7</td>
<td>0.74 (0.63, 1)</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>External rotation at 0° abduction</td>
<td>55 (16)</td>
<td>0.91 (0.84, 1)*</td>
<td>5</td>
<td>13</td>
<td>0.91 (0.86, 1)*</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>External rotation at 90° abduction</td>
<td>90 (12)</td>
<td>0.81 (0.65, 1)</td>
<td>5</td>
<td>14</td>
<td>0.72 (0.60, 1)</td>
<td>6</td>
<td>18</td>
</tr>
<tr>
<td>Internal rotation at 90° abduction</td>
<td>51 (10)</td>
<td>0.87 (0.73, 1)*</td>
<td>4</td>
<td>11</td>
<td>0.62 (0.47, 1)</td>
<td>6</td>
<td>18</td>
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<tr>
<td>Horizontal adduction</td>
<td>36 (12)</td>
<td>0.89 (0.70, 1)*</td>
<td>4</td>
<td>12</td>
<td>0.47 (0.32, 1)</td>
<td>9</td>
<td>26</td>
</tr>
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<td><strong>Supine PROM:</strong></td>
<td></td>
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</tr>
<tr>
<td>Abduction</td>
<td>176 (14)</td>
<td>0.91 (0.83, 1)*</td>
<td>4</td>
<td>12</td>
<td>0.88 (0.82, 1)*</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>Flexion</td>
<td>177 (6)</td>
<td>0.85 (0.72, 1)*</td>
<td>3</td>
<td>7</td>
<td>0.78 (0.68, 1)</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>External rotation at 0° abduction</td>
<td>68 (16)</td>
<td>0.94 (0.88, 1)*</td>
<td>4</td>
<td>11</td>
<td>0.85 (0.77, 1)*</td>
<td>7</td>
<td>18</td>
</tr>
<tr>
<td>External rotation at 90° abduction</td>
<td>103 (11)</td>
<td>0.86 (0.64, 1)</td>
<td>5</td>
<td>13</td>
<td>0.49 (0.35, 1)</td>
<td>9</td>
<td>24</td>
</tr>
<tr>
<td>Horizontal adduction</td>
<td>43 (10)</td>
<td>0.85 (0.59, 1)</td>
<td>4</td>
<td>12</td>
<td>0.36 (0.21, 1)</td>
<td>9</td>
<td>25</td>
</tr>
</tbody>
</table>

* Movements that achieved criterion value of an ICC with a lower band of the one-sided 95% confidence interval ≥ 0.70. Shaded areas are the ICC values that achieved the criterion value of reliability and the corresponding SEM and MCD values.
### Table 4. Reliability with One-sided 95% Confidence Intervals, Standard Error of the Measurement (SEM), and Minimum Clinical Difference (MCD). Values are shown for a single rater and two raters when examining patients with shoulder pathology. (N = 11)

<table>
<thead>
<tr>
<th>Movement</th>
<th>Average Range of Motion (SD)</th>
<th>Intra-rater reliability</th>
<th>Intra-rater SEM</th>
<th>MCD for single rater</th>
<th>Inter-rater reliability</th>
<th>Inter-rater SEM</th>
<th>MCD for two raters</th>
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</thead>
<tbody>
<tr>
<td><strong>Standing AROM:</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Abduction</td>
<td>160 (15)</td>
<td>0.93 (0.85, 1)*</td>
<td>4</td>
<td>11</td>
<td>0.57 (0.33, 1)</td>
<td>10</td>
<td>28</td>
</tr>
<tr>
<td>Extension</td>
<td>44 (9)</td>
<td>0.65 (0.35, 1)</td>
<td>5</td>
<td>14</td>
<td>0.47 (0.31, 1)</td>
<td>6</td>
<td>18</td>
</tr>
<tr>
<td>Flexion</td>
<td>151 (8)</td>
<td>0.63 (0.41, 1)</td>
<td>5</td>
<td>14</td>
<td>0.55 (0.29, 1)</td>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td>Seuction</td>
<td>159 (13)</td>
<td>0.78 (0.48, 1)</td>
<td>7</td>
<td>18</td>
<td>0.47 (0.33, 1)</td>
<td>10</td>
<td>28</td>
</tr>
<tr>
<td><strong>Supine AROM:</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Abduction</td>
<td>153 (27)</td>
<td>0.95 (0.91, 1)*</td>
<td>6</td>
<td>16</td>
<td>0.91 (0.86, 1)*</td>
<td>9</td>
<td>24</td>
</tr>
<tr>
<td>Flexion</td>
<td>163 (13)</td>
<td>0.90 (0.84, 1)*</td>
<td>4</td>
<td>11</td>
<td>0.89 (0.82, 1)*</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>External rotation at 0° abduction</td>
<td>45 (15)</td>
<td>0.89 (0.78, 1)*</td>
<td>5</td>
<td>15</td>
<td>0.76 (0.65, 1)</td>
<td>8</td>
<td>22</td>
</tr>
<tr>
<td>External rotation at 90° abduction</td>
<td>83 (19)</td>
<td>0.93 (0.88, 1)*</td>
<td>5</td>
<td>14</td>
<td>0.89 (0.82, 1)*</td>
<td>7</td>
<td>18</td>
</tr>
<tr>
<td>Internal rotation at 90° abduction</td>
<td>42 (9)</td>
<td>0.69 (0.32, 1)</td>
<td>5</td>
<td>14</td>
<td>0.39 (0.24, 1)</td>
<td>7</td>
<td>20</td>
</tr>
<tr>
<td>Horizontal adduction</td>
<td>29 (8)</td>
<td>0.82 (0.61, 1)</td>
<td>4</td>
<td>10</td>
<td>0.59 (0.44, 1)</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td><strong>Supine PROM:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abduction</td>
<td>161 (26)</td>
<td>0.94 (0.89, 1)*</td>
<td>7</td>
<td>18</td>
<td>0.92 (0.88, 1)*</td>
<td>8</td>
<td>21</td>
</tr>
<tr>
<td>Flexion</td>
<td>171 (12)</td>
<td>0.92 (0.85, 1)*</td>
<td>3</td>
<td>9</td>
<td>0.88 (0.81, 1)*</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>External rotation at 0° abduction</td>
<td>59 (15)</td>
<td>0.94 (0.88, 1)*</td>
<td>4</td>
<td>11</td>
<td>0.86 (0.78, 1)*</td>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td>External rotation at 90° abduction</td>
<td>94 (19)</td>
<td>0.95 (0.90, 1)*</td>
<td>4</td>
<td>12</td>
<td>0.89 (0.82, 1)*</td>
<td>7</td>
<td>18</td>
</tr>
<tr>
<td>Horizontal adduction</td>
<td>39 (8)</td>
<td>0.89 (0.78, 1)*</td>
<td>3</td>
<td>8</td>
<td>0.70 (0.57, 1)</td>
<td>5</td>
<td>14</td>
</tr>
</tbody>
</table>

* Movements that achieved criterion value of an ICC with a lower band of the one-sided 95% confidence interval ≥ 0.70. Shaded areas are the ICC values that achieved the criterion value of reliability and the corresponding SEM and MCD values.
stabilization techniques to control for accessory scapulothoracic motion was superior for measurement.\textsuperscript{15} Measurement of glenohumeral internal rotation used during the current study used stabilization of the scapula in order to identify the point where scapular motion commenced, at which point the end of range of motion was deemed present and goniometric measurement was taken. Scapular stabilization was not possible to maintain by a single person during goniometric measurement of passive range of motion measurement, so this movement was not included. The current authors found that glenohumeral internal rotation could not be reliably measured when performed as it would be in a typical clinical setting by a single evaluator. This is in contrast to Awan et al.\textsuperscript{15} whose protocol used two people in the measurement process, one for positioning and one to perform the measurement.

Comparison of our results to previous studies that used the goniometer as the measurement device is limited by the lack of reported confidence intervals in other studies.\textsuperscript{2,5,6,11} The present study's findings are in accordance with the results from Hayes et al\textsuperscript{8} in that the movements of intra-rater reliability for standing AROM flexion and inter-rater reliability of standing AROM flexion and abduction fall below the threshold ICC of 0.70 in shoulders with pathology.

This study also highlights the importance of including confidence intervals along with the ICC point estimates when evaluating reliability. Only 7 of 15 common shoulder ROM measurements met the predetermined level of reliability in both groups for a single evaluator. Reliable measurements were achieved using multiple raters for only 4 ROM measurements in both groups, AROM and PROM abduction and external rotation at 0° abduction. The confidence intervals provide a measure of the precision of the estimate and the majority of previous studies have not presented them. The point estimate alone is not sufficient to determine if the measurement exceeds the ICC threshold of 0.70. This study used an a priori specification to determine an adequate sample size and power to evaluate if ICC values meet the ICC threshold of 0.70.

Variation in reliability values can arise from several sources including the inaccurate or inconsistent land-marking during goniometer placement and lack of stabilization of the shoulder girdle to prevent compensatory scapulothoracic movements during rotations. Movements in supine allow for support of the trunk permitting greater relaxation of the participant and stabilization of the shoulder girdle especially in the evaluation of PROM. The assessment of AROM in positions of sitting or standing while providing an evaluation in a functional position also introduces muscular strength as a potential limiting factor to the maximal attained range of motion. Limited range of motion in a gravity dependent position, such as standing, then needs to be further differentiated between strength and range of motion as limiting factors to assist in devising a treatment program. The assessment of ROM in supine creates different gravity effects and may be complementary to the assessment in standing due to the alterations of muscle strength requirements. The use of a second person to provide the stabilization on the assessment of rotation movements especially in 90° abduction, as found by Awan et al\textsuperscript{15}, may need to be encouraged, particularly for research, where it may be important to detect small, but important differences between patient groups. The present study also incorporated measures to limit error due to a warm-up effect, but may not have removed all effects. This finding supports the practice of providing a sufficient warm-up to the area to be assessed before evaluation. Greater variability in PROM than AROM may result from variation in the amount of force used to attain full range, especially for inter-rater reliability, and therefore active movements may be preferable to passive movements in order to evaluate change.

It is uncertain if the movements with the lowest reliability values can be improved with greater training, but it does highlight the importance of training sessions for evaluators and the reporting of this information when performing clinical studies. Therefore, it seems reasonable for research investigators to include a reliability sub-study to confirm the consistency of evaluators and to establish the minimal clinical difference for a given study population. As the values obtained in this study are from a combined population with normal shoulders and shoulders with chronic stable pathology, any study
evaluating shoulders with acute conditions may have greater variation in values.

The setting of a minimally acceptable level for both intra and inter-rater reliability and testing to determine whether those levels could be achieved was a unique aspect of this study. Hypothesis testing in the absence of a criterion value only tests if values are different than zero. We specifically evaluated if goniometric shoulder assessment can achieve clinically useful reliability values using a pre-determined criterion value of ICC ≥ 0.70.

In this study, reliability with a goniometer was difficult to achieve using multiple raters, a trend consistent with other studies. The movements that did not meet the criterion value may be unable to accurately reflect change over time and therefore should be used with caution as primary outcomes in research and clinical practice for this purpose. As standard goniometers are not the only measurement method available for range of motion evaluation, there is still room to refine reliability further through evaluation of other apparatus such as electro-goniometers or inclinometers.

It is important therefore to highlight and demonstrate how the information from this study can be used practically in the clinical and research setting. The intra-rater SEM provides the range of values that can be expected on re-testing for a single evaluator. For example; assume a single rater assesses active standing abduction, a movement that achieved the reliability threshold, obtains a value of 135°. The intra-rater SEM, four degrees, suggests that if the same rater repeated that measurement, and there was no expectation that the subject’s AROM had truly changed, the range of possible values could be 131° to 139°. This range of values could impact outcome measure scoring systems for functional assessment of the shoulder where points are assigned to the actual range of motion value, as in the Constant and UCLA Shoulder Scores.

The inter-rater SEM gives the range of potential error in different raters’ measurements. This value has practical implications on the reporting and comparison of results from independent assessments, as can occur in worker compensation or insurance claims. In either scenario, an independent assessment, concurrent with community rehabilitation, is not uncommon as part of the routine practice of case management. Active supine abduction, a measurement that met the reliability criterion, has a potential variability in measurement between two raters on a measured value of 135° of 111° to 159°. Passive supine horizontal adduction, a movement that did not meet the criterion threshold, has a range of values of 121° to 149° on a measured value of 135°. If the extremes of possible values were obtained in this scenario, the variability could be misattributed as a lack of sincerity of effort or irritability of the underlying tissue or injury when in fact it is just the inherent error in the measurement process and not a reflection of the capability of the person being assessed.

In clinical research, the MCD for two raters has implications for evaluating the superiority of one treatment regimen over another. For example, using a hypothetical randomized controlled trial of two post-operative rehabilitation protocols after mini-open rotator cuff surgery, treatment regimen 1 produces a statistically significant gain in range of motion for supine active abduction, forward flexion, and external rotation in adduction. The MCD can be used to determine if the statistically significant difference in treatment is in excess of the measurement error and therefore, also clinically meaningful.

There are several limitations in the current study that need to be addressed. The sample size was achieved in the normal shoulder group, but unfortunately, sample size could not be achieved in the shoulder pathology group within the time frame available to complete the study. A lack of movements achieving the a priori established ICC value in the shoulder pathology group could be due in part to insufficient power to find a statistical significantly association. A full evaluation of all AROM and PROM glenohumeral rotations at 90° abduction in the two patient test positions limits comprehensive knowledge translation to clinical practice. While there is limited reliability using a standard goniometer, these limitations cannot be translated to other methods of measuring range of motion; therefore evaluation with other measurement tools is recommended considering the prominence that measurement plays in clinical practice and research.
CONCLUSIONS
Intra-rater evaluation can achieve acceptable reliability in the greatest number of movements: standing AROM abduction; supine AROM abduction, flexion, and external rotation (ER) at 0° abduction; and supine PROM abduction, flexion and ER at 0° abduction. Across the groups with normal and shoulder pathology, inter-rater evaluation met the criterion level for reliability for four movements performed in supine: AROM and PROM of abduction and external rotation at 0° abduction. These movements should be considered as acceptable for measuring and quantifying change over time and as primary outcomes in research.

REFERENCES
### Appendix 1: Details of Testing Positions and Goniometer Placement

#### Test Positions for AROM in Standing

<table>
<thead>
<tr>
<th>Test Movement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward Flexion</td>
<td>The movement included scapular motion with measurement made with full elbow extension and motion leading with the thumb along a path in the sagittal plane. The goniometer was centered in the middle of the glenoid fossa with the arms aligned with the lateral epicondyle and the vertical line in the coronal plane.</td>
</tr>
<tr>
<td>Abduction</td>
<td>This movement included scapular motion with the measurement made with full elbow extension and motion leading with the thumb in the coronal plane. The goniometer was centered in the middle of the posterior glenohumeral joint line and the arms were aligned with the lateral epicondyle and the vertical line of the sagittal plane.</td>
</tr>
<tr>
<td>Scaption</td>
<td>Defined as elevation through abduction in the plane of the scapula defined to be 30-45° anterior to the coronal plane. This movement was performed with full elbow extension and movement leading with the thumb. The goniometer placement was the same as used when measuring abduction in standing.</td>
</tr>
<tr>
<td>Extension</td>
<td>Shoulder extension was measured with full elbow extension and forearm in neutral pronation/supination. Subject moved both arms at the same time to minimize trunk compensation movements. The goniometer placement was the same as used when measuring flexion in standing.</td>
</tr>
</tbody>
</table>

#### Test Positions for AROM and PROM in Supine

PROM and AROM were measured for each of the movements in supine except for internal rotation where PROM was not performed. For all PROM measurements, overpressure was applied by the evaluator to achieve full allowable motion.

<table>
<thead>
<tr>
<th>Test Movement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward Flexion</td>
<td>Movement in this position was measured with full elbow extension and leading with the thumb. The goniometer was centered in the middle of the glenoid fossa with the arms aligned with the lateral epicondyle of the humerus and horizontal along the midline of the trunk.</td>
</tr>
<tr>
<td>Appendix 1</td>
<td>Continued</td>
</tr>
<tr>
<td>-----------------</td>
<td>-------------------------------------------------</td>
</tr>
<tr>
<td><strong>Abduction</strong></td>
<td>This movement was measured in the coronal plane with full elbow extension and leading with the thumb. The goniometer was centered in the middle of the glenoid fossa on the anterior aspect of the shoulder joint. The stationary arm was aligned parallel to the spine and the active arm along the shaft of the humerus.</td>
</tr>
<tr>
<td><strong>External Rotation in 0° Abduction</strong></td>
<td>This movement was measured with the humerus positioned parallel to the spine or maximum adduction if the person could not achieve 0°. Towels were positioned as needed under the upper arm to bring the humerus in line with the coronal plane. The elbow was flexed to 90° with the forearm in neutral supination/pronation and the person was instructed to maintain adduction. The goniometer was centered at the olecranon with the arms aligned with the shaft of the ulna and the vertical axis of the movement plane.</td>
</tr>
<tr>
<td><strong>External Rotation at 90° Abduction</strong></td>
<td>The arm was initially passively positioned in 90° of pure abduction and towels were used, as needed, under the upper arm to bring the humerus level with the coronal plane as the starting position. The elbow was flexed to 90° with the forearm in neutral supination/pronation. The goniometer placement was the same as that used during measurement of external rotation at 0°.</td>
</tr>
<tr>
<td><strong>Internal Rotation at 90° Abduction</strong></td>
<td>The initial arm placement was as per external rotation at 90°. Maximal movement was defined at the point when scapular ante-tilt could not be corrected with verbal cueing under manual stabilization by therapist. This was observed when contact between the posterior aspect of the shoulder and the assessment table could not be maintained. The goniometer placement was the same as that used during measurement of external rotation at 0°.</td>
</tr>
<tr>
<td><strong>Horizontal Adduction</strong></td>
<td>Starting position of the arm was passive placement in 90° flexion and internal rotation so the forearm aligns horizontally across the body at the level of the shoulders. The elbow was flexed to 90° and the forearm pronated. Maximal movement was defined at the commencement of scapular protraction observed when contact between the posterior aspect of the shoulder and the assessment table could no longer be maintained. Manual stabilization was used on the scapula. The goniometer was positioned over the acromioclavicular joint from the superior aspect and the arms were aligned with the shaft of the humerus and the vertical axis.</td>
</tr>
</tbody>
</table>
ABSTRACT

**Background:** Quadriceps activation failure is common in patients with tibiofemoral osteoarthritis (TFOA) and has been reported to occur bilaterally following acute and chronic knee injuries. Sensory transcutaneous electrical stimulation (TENS) applied to the knee has increased ipsilateral quadriceps activation, yet it remains unknown if repeated sensory TENS treatments affect activation in the contralateral quadriceps.

**Objective:** To determine the effects of unilateral TENS treatment to the involved leg, in conjunction with 4-weeks of therapeutic exercise, on volitional quadriceps activation in the contralateral leg.

**Methods:** Thirty-three patients with radiographically diagnosed TFOA were randomly assigned to the TENS, placebo, and the control groups. The involved leg was defined as the knee with highest degree of radiographically assessed TFOA. All participants completed a supervised 4-week lower extremity exercise program for the involved leg only. TENS and placebo TENS were worn throughout the rehabilitation sessions as well as during daily activities for those groups on the involved leg. Quadriceps central activation ratio (CAR), a measure of volitional muscular activation, was assessed in the uninvolved leg at baseline, 2-weeks and 4-weeks following the initiation of the intervention.

**Results:** There were no differences between groups for quadriceps CAR (P = 0.3).

**Discussion:** Although significant differences were not found, strong to moderate within group effect sizes were calculated for the TENS group at 2 (d = .87) and 4 weeks (d = .54), suggesting that significant differences may be found in a larger population.

**Conclusions:** Contralateral quadriceps CAR was not affected following a 4-week unilateral disinhibitory intervention in this sample.

**Key Words:** Voluntary activation, Arthrogenic muscle inhibition, Pain, Strength
INTRODUCTION

Quadriceps activation failure is common following a variety of acute knee injuries as well as in degenerative conditions such as tibiofemoral osteoarthritis. This quadriceps activation failure has been reported to affect physical function and is proposed to be a factor leading to increased joint degeneration due to inability to adequately absorb shock. Different neural mechanisms causing decreased motor output in the uninjured quadriceps musculature surrounding an injured knee have been proposed as the underlying cause of quadriceps activation failure in these populations. There is evidence to suggest that both spinal reflexive mechanisms and cortical mechanisms may alter quadriceps excitability in people with knee joint pathology.

Bilateral quadriceps activation deficits following unilateral knee joint injury may be further evidence to suggest that the central nervous system is actively engaged in altering muscle function. Hart et al. reported that quadriceps volitional activation is decreased in both involved and uninvolved legs of patients with anterior cruciate ligament deficits, anterior cruciate ligament reconstructions and anterior knee pain when compared to healthy matched controls. In addition, Berth et al. has reported bilateral quadriceps activation deficits in patients with unilateral tibiofemoral osteoarthritis when compared to healthy matched controls. It is possible that chronic bilateral inhibition may over time lead to serious knee joint damage in the uninvolved limb, by decreasing the patient’s ability to appropriately attenuate shock in bilateral lower extremities.

It may be necessary to target the central nervous system with interventions specifically aimed at increasing quadriceps muscle activation in patients with arthrogenic muscle inhibition. Sensory transcutaneous electrical nerve stimulation (TENS), conventionally used for pain modulation has previously been reported to increase the reflexive excitability of the central nervous system in the ipsilateral quadriceps motor neuron pool following experimentally induced joint effusion and to increase the ipsilateral volitional quadriceps activation in people with tibiofemoral osteoarthritis. Currently, the neural mechanisms modulating motor neuron pool excitability in the presence of TENS are unknown, yet it is hypothesized that TENS causes alterations in afferent stimuli which are interpreted by interneurons as excitatory. This increase in excitatory afferent signal is hypothesized to allow for excitation of the previously inhibited motor neuron pool by overriding the substantially weaker inhibitory signal. The TENS parameters used to increase muscle activation are identical to pain modulation parameters, suggesting that this conventional modality may have a new indication independent from altering pain. Although there is evidence to suggest the central nervous system seems to engage bilateral quadriceps inhibition following unilateral joint knee injury, it remains unknown if efforts to unilaterally disinhibit the involved quadriceps motor neuron pool will result in disinhibition of the contralateral or uninvolved quadriceps.

Therefore, the primary aim of the current study was to determine if disinhibitory TENS treatment in conjunction with 4-weeks of therapeutic exercise to the involved leg would alter quadriceps activation in the contralateral leg in patients with tibiofemoral osteoarthritis in at least one knee. Additionally, the authors sought to determine if changes in quadriceps activation in the leg contralateral leg would correlate with changes in quadriceps activation in the treatment leg over a 4 week period. The authors hypothesized that quadriceps activation would increase in the contralateral leg of patients receiving TENS compared to the placebo and control groups, and that changes in quadriceps activation in the treated leg would correlate with quadriceps activation in the contralateral leg.

METHODS

Participants identified in this study were part of a larger randomized controlled trial evaluating disinhibitory interventions on function in people with tibiofemoral osteoarthritis (TFOA). Prior to randomization into one of the three intervention groups (TENS, Placebo TENS, Control), participants were stratified by the central activation ratio (CAR) of their involved quadriceps and by the radiographic severity of TFOA as assessed by a single fellowship
trained orthopaedic surgeon using the Kellgren-Lawrence (K-L) grading system. All participants regardless of group assignment participated in a 4-week lower extremity strengthening program, supervised by a licensed physical therapist or a certified athletic trainer. Main outcome measures in the present study included maximal quadriceps volitional activation, as measured by the CAR, and maximal voluntary isometric (MVIC) torque in the uninvolved leg at 2 and 4-weeks of the intervention. Secondary outcome measures included pain scores measured during the MVIC with a visual analog scale, in the uninvolved leg at 2 and 4-weeks, and the relationship of percent change scores in CAR and MVIC of both legs at the 2 and 4-week time points. The investigator conducting all of the outcome measures was blinded to group assignment. Participants in both the placebo and active TENS groups were not informed of their group assignment. (Figure 1)

Participants
Forty-nine participants volunteered for this current study and 33 participants were randomized into groups and used in the final analysis (Table 1). Participants were included if they had been clinically diagnosed with TFOA, an involved leg K-L score between 1-4 and quadriceps activation failure defined as a CAR of less than 90%. The involved knee was considered the knee with the greatest radiographic evidence of osteoarthritis, and in the case that both knees were graded similarly; the participant was asked which knee caused them the most dysfunction. Participants with total knee reconstructions were removed from this analysis. A mandatory 2-week washout period was implemented for all participants who previously had a corticosteroid or hyaluronic acid injection. This 2-week washout period was determined from previously published data evaluating half-life periods for both corticosteroid and hyaluronic acid. The use of prescription and over-the-counter medications for pain relievers and anti-inflammatory drugs were monitored throughout the study and participants were asked to discontinue the use of all non-essential pain medication 12-hours prior to therapy sessions and 24-hours prior to all testing sessions as previously reported.

Participants with a diagnosed heart condition limiting exercise, altered sensation over the anterior knee, and lower body surgery or knee trauma in the past 6 months were excluded. This study was approved by the Institutional Review Board (HSR-13360) prior to subject enrollment and written informed consent was obtained prior to participation.

Table 1. Baseline Demographic Means (SD).

<table>
<thead>
<tr>
<th></th>
<th>TENS</th>
<th>Placebo</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (Males/ Females)</td>
<td>5/5</td>
<td>3/8</td>
<td>5/7</td>
</tr>
<tr>
<td>Mass (Kg)</td>
<td>81.3 (10)</td>
<td>86.8 (27)</td>
<td>83.6 (18.7)</td>
</tr>
<tr>
<td>Age (Years)</td>
<td>60.3 (11.9)</td>
<td>58.7 (12.2)</td>
<td>58.3 (11.8)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>171.1 (7.1)</td>
<td>171.1 (7.1)</td>
<td>171 (11.1)</td>
</tr>
<tr>
<td>Body Mass Index</td>
<td>28.1 (4.8)</td>
<td>29.9 (10.2)</td>
<td>28.6 (5.6)</td>
</tr>
<tr>
<td>Involve Kellgren-Lawrence Score</td>
<td>3.1 (0.9)</td>
<td>3.2 (7.5)</td>
<td>2.9 (1.1)</td>
</tr>
<tr>
<td>Uninvolved Kellgren-Lawrence Score</td>
<td>1.6 (1.3)</td>
<td>2.5 (0.9)</td>
<td>1.6 (1.4)</td>
</tr>
<tr>
<td>Involved Baseline CAR</td>
<td>0.79 (0.13)</td>
<td>0.77 (0.8)</td>
<td>0.80 (0.08)</td>
</tr>
<tr>
<td>Involved Baseline MVIC</td>
<td>1.80 (0.8)</td>
<td>1.41 (0.7)</td>
<td>1.9 (0.8)</td>
</tr>
<tr>
<td>Involved Baseline Pain</td>
<td>17.2 (15.3)</td>
<td>21.0 (13.5)</td>
<td>22.8 (16.2)</td>
</tr>
</tbody>
</table>

CAR= Central Activation Ratio, MVIC= Maximal Voluntary Isometric Contraction
Figure 1. Consort Flow Chart. K-L = Kellgren Lawrence Score, CAR = Central activation ratio. All Stratified values refer to the involved leg.
and participants were instructed to wear these units during all 12 therapeutic exercise sessions and at least 8 hours a day during activities of daily living. Active TENS consisted of a sensory continuous, biphasic pulsatile current (frequency of 150 Hz, and phase duration of 150μs). Four separate 2 × 2 inch self-adhesive electrodes (Re-ply reusable electrodes, Uni-Patch, Wabasha, MN) were used to deliver the TENS stimulation to the involved knee joint of the participants. 21 Subjects used self-selected amplitude that resulted in a strong sensory, but submotor stimulation in the TENS group. Placebo TENS was administered with the same instruments, but the unit was programmed to discontinue the current 30 seconds after the stimulation had been started. All other features of the placebo unit were identical.

The units in the active TENS group were set to deliver a continuous TENS current. Participants were instructed on how to increase and decrease amplitude, which could be adjusted between 1 and 60 mA. Amplitude was set to a strong but comfortable sensory stimulation intensity not strong enough to elicit muscle contraction. If participants experienced a muscle contraction from the TENS they were instructed to decrease the intensity until no muscle contraction was felt, while still maintaining a sensory stimulus. Participants were instructed to maintain this sensation throughout each treatment session by adjusting intensity. 21 Placebo TENS patients received the same stimulators, and were instructed to increase the intensity until they felt a sensory stimulation. Following 30 seconds of stimulation, placebo TENS units were programmed to automatically gradually decrease the current over 10 seconds until no electricity was emitted. Participants were told that the current parameters were set to a subsensory level and the unit was delivering the treatments as long as the indicator light was on. Participants were instructed to maintain the intensity at a level of “5” throughout the day. Compliance with both the active and placebo TENS was collected with self-report data sheets, upon which participants documented the number of hours the unit was used each day.

Maximal Voluntary Isometric Contraction Torque, Central Activation Ratio and Knee Pain Measurements
For both the MVIC and CAR testing, participants were secured to a dynamometer (Biodex™ System 3 Pro; Biodex™ Medical Systems, Shirley, NY) with hips flexed to 85°, and 70° of knee flexion. 20 All landmarks were properly aligned with the dynamometer, while the stimulating electrodes were positioned over the distal vastus medialis and proximal vastus lateralis and secured to the thigh with an elastic bandage. 20

Prior to testing, participants pedaled a stationary bicycle at a self-selected speed for 5 minutes, and a graded isometric warm-up was conducted on the dynamometer in order to assure that subjects were able to exert maximal effort during the test and were accustomed to the electrical stimulus. 20,21,23 In addition to submaximal trials, participants performed 2 to 4 practice MVICs until the investigator was confident that each subject was able to exert maximal effort.

During CAR testing, an exogenous electrical stimulus was applied to the quadriceps muscles using a Grass stimulator (S88, Grass Telefactor, West Warwick, RI) and a stimulation isolation unit (SIU8T, Warwick, RI) to elicit a superimposed twitch that which would be used to determine the maximal force generation capacity of the quadriceps. A superimposed electrical stimulation was delivered by the test administrator when a maximal plateau in force had been reached. 20,21,23 As previously reported 20,21,23 the exogenous stimulus consisted of a 100ms train of 10 stimuli at 100 Hz consisting of a phase duration of 600μs applied to each subject at 125 volts. Two trials, separated by a 60 second rest period, were performed to ensure that 2 acceptable trials could be averaged at each testing session. 21

Knee pain was assessed during a MVIC trial separate from those using a supramaximal stimulation to assess quadriceps central activation and MVIC. During this MVIC, participants were asked to think about their knee pain during the MVIC and rate the intensity on a 10cm visual analog scale. The left side of the line indicated “absolutely no pain” while the right side indicated the “worst pain imaginable”. 21

Transcutaneous Electrical Nerve Stimulation
The Select System TENS unit (EMPI, Inc., St. Paul, MN) was used in both the active and placebo groups and participants were instructed to wear these units during all 12 therapeutic exercise sessions and at least 8 hours a day during activities of daily living. Active TENS consisted of a sensory continuous, biphasic pulsatile current (frequency of 150 Hz, and phase duration of 150μs). Four separate 2 × 2 inch self-adhesive electrodes (Re-ply reusable electrodes, Uni-Patch, Wabasha, MN) were used to deliver the TENS stimulation to the involved knee joint of the participants. 21 Subjects used self-selected amplitude that resulted in a strong sensory, but submotor stimulation in the TENS group. Placebo TENS was administered with the same instruments, but the unit was programmed to discontinue the current 30 seconds after the stimulation had been started. All other features of the placebo unit were identical.

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Therapeutic Exercise
Participants in all three groups received quadriceps strengthening for their involved leg three times per
The peak force \((F_{SIB} + F_{MVIC})\) value and the maximal voluntary contraction value \((F_{MVIC})\) were calculated from the mean of the two best separate trials at each time in the series, when the superimposed burst was applied. \(F_{MVIC}\) was calculated from a 0.15 second time epoch immediately prior to the administration of the exogenous electrical stimulus. All MVICs were reported separately as Nm/Kg. The mean value of the voluntary force plateau was divided by the peak value of the force produced by the superimposed burst. Percent change scores were calculated by subtracting the posttest measurement from the baseline measurement and dividing this difference score by the baseline measurement. Pain scores were quantified by measuring tick marks in mm from “absolutely no pain” with higher numbers indicating higher perceived pain (100 mm max).

**Statistical Analysis**

Four separate paired t-tests were performed to assess if differences existed in K-L scores, CAR, MVIC, and pain values between involved and uninvolved legs among the entire sample. A Bonferroni correction \((P = 0.05/4 = 0.013)\) was used to insure the family wise error rate was maintained. Three separate 3 x 3 analyses of variance with repeated measures on time were conducted to determine if quadriceps CAR, MVIC and pain scores were different in the uninvolved leg between intervention groups over time. Sheffe’s tests were used post hoc to evaluate

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**Table 2. Outcome Measure Means (SD) Over the 4 Week Intervention for the Contralateral Side.**

<table>
<thead>
<tr>
<th></th>
<th>Baseline Control</th>
<th>Baseline Placebo</th>
<th>Baseline TENS</th>
<th>2 - Weeks Control</th>
<th>2 - Weeks Placebo</th>
<th>2 - Weeks TENS</th>
<th>4-weeks Control</th>
<th>4-weeks Placebo</th>
<th>4-weeks TENS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAR</td>
<td>0.84 (0.12)</td>
<td>0.85 (0.16)</td>
<td>0.86 (0.11)</td>
<td>0.84 (0.11)</td>
<td>0.84 (0.14)</td>
<td>0.93 (0.03)</td>
<td>0.81 (0.17)</td>
<td>0.82 (0.17)</td>
<td>0.91 (0.07)</td>
</tr>
<tr>
<td>MVIC</td>
<td>2.4 (0.7)</td>
<td>1.97 (0.8)</td>
<td>2.47 (0.88)*</td>
<td>2.6 (0.6)</td>
<td>1.93 (0.87)</td>
<td>2.99 (0.5)*</td>
<td>2.4 (0.8)</td>
<td>1.9 (0.81)</td>
<td>2.8 (0.7)*</td>
</tr>
<tr>
<td>Pain</td>
<td>5.3 (7.0)</td>
<td>10.1 (6.7)</td>
<td>8.2 (12.9)</td>
<td>2.7 (3.3)</td>
<td>11.8 (11.4)</td>
<td>3.6 (3.7)</td>
<td>5.5 (8.1)</td>
<td>10.8 (12.4)</td>
<td>2 (2.3)</td>
</tr>
</tbody>
</table>

* Significantly higher than the placebo group \(P = 0.003\), TENS = Transcutaneous electrical nerve stimulation, CAR = Central Activation Ratio, MVIC = Maximal voluntary isometric contraction

---

week during a 4-week treatment period, for a total of 12 sessions. The therapeutic exercise sessions were supervised by either an experienced certified athletic trainer or licensed physical therapist. The clinical goals of the 4-week rehabilitation program were to 1) increase lower extremity knee, hip, and ankle range of motion 2) increase quadriceps, hamstring, hip abductor, hip adductor, gastrocnemius and soleus strength and 3) increase function through squat, stair stepping and balance exercises, as well as 4) decrease pain in the subjects involved leg, specifically. Strengthening exercises were systematically progressed using the daily adjustable progressive resistive exercise (DAPRE) system (Table 2). All participants were challenged to increase weight as directed by the DAPRE system, while maintaining no more than minimal discomfort throughout the exercise session. Although the therapeutic exercise was intentionally targeting the quadriceps of the involved leg some required the use of both legs and the complete program is described in Table 2.

**Data Analysis**

All raw torque data was low-pass filtered at 15 Hz. CAR was calculated by dividing the force measurements of the maximal voluntary contraction \((F_{MVIC})\) by that of the force produced by the superimposed burst \((F_{SIB})\) plus the MVIC \((F_{MVIC})\) as previously performed.\(^{21,23}\)

**Equation 1** \(\text{CAR} = \frac{(F_{MVIC})}{(F_{SIB} + F_{MVIC})}\)
multiple comparisons when appropriate. Cohen’s standardized effect sizes with 95% confidence intervals were calculated for all groups at each post test for CAR, MVIC (Nm/kg) and pain by subtracting the posttest score from the baseline score and dividing the difference by the pooled standard deviation. Additionally, Pearson product moments were calculated to assess the relationship between the change in involved and the change in unininvolved CAR scores at 2 and 4 weeks. The alpha level was set a priori at $P < 0.05$. All statistical analyses were performed with SPSS for windows (Version 16.0; SPSS, Chicago, Illinois).

**RESULTS**

K-L Scores were significantly higher in the involved leg when compared to the unininvolved leg ($3 \pm 0.9$ vs $1.9 \pm 1.3$, $P < 0.01$) in all participants. Additionally, the involved leg displayed lower CARs ($0.79 \pm 0.1$ vs $0.85 \pm 0.13$, $P = 0.007$) and normalized MVICs ($1.7 \pm 0.75$ vs $2.3 \pm 0.8$, $P < 0.001$) and higher pain scores ($20.4 \pm 14.8$ vs $7.75 \pm 9.1$, $P < 0.001$) compared to the unininvolved leg at baseline.

No significant differences were found in the unininvolved limb between groups ($P = 0.3$, $1-\beta = 0.2$) or over time ($P = 0.2$, $1-\beta = 0.3$) for CAR. No group by time interaction was found for CAR ($P = 0.5$, $1-\beta = 0.3$). Strong to moderate effect sizes were found for CAR at 2 ($d = 0.87$) and 4-weeks ($d = 0.54$) compared to baseline scores respectively (Table 2).

Effect sizes were small at both 2 and 4-weeks for CAR in the placebo and control group. It should be noted that effect sizes all cross 0 indicating no definitive effect is present (Table 3).

There were no significant differences in MVIC over time, yet there was a main effect for group ($P = 0.03$, $1-\beta = 0.7$). TENS MVICs were significantly higher than the placebo MVIC ($P = 0.04$), while control MVICs did not statistically differ from TENS ($P = 0.6$) or the placebo group ($P = 0.2$). Moderate within group effect sizes were found at 2-weeks for the TENS groups ($d = 0.73$), while all other effect sizes were found to be small or weak. Similar to the CAR, 95% confidence intervals for the MVIC all crossed 0, suggesting that the magnitudes of these effect sizes are not definitive.

Similarly to MVIC, there were no significant differences over time for pain ($P = 0.5$, $1-\beta = 0.2$), while there was a significant main effect for pain between groups ($P = 0.03$, $1-\beta = 0.7$). Multiple comparisons found no statistical differences between control and placebo ($P = 0.06$) or control and TENS groups ($P = 0.99$). Additionally there was no difference between TENS and placebo ($P = 0.9$). Moderate effect sizes, all with 95% confidence intervals that cross 0, for pain were found in the TENS group at 4-weeks ($d = -0.67$), while all other pain effects were weak or small (refer to Table 3).

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**Table 3. Effect Sizes (95% Confidence Intervals) for Outcome Means Over the 4 Week Intervention for the Contralateral Side.**

<table>
<thead>
<tr>
<th></th>
<th>2-weeks</th>
<th></th>
<th>4-weeks</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Placebo</td>
<td>TENS</td>
<td>Control</td>
</tr>
<tr>
<td>CAR</td>
<td>0.0 (-0.8 to 0.8)</td>
<td>-0.07 (-0.9 to 0.77)</td>
<td>0.87 (-0.08 to 1.75)</td>
<td>-0.2 (-1.0 to 0.61)</td>
</tr>
<tr>
<td>MVIC</td>
<td>0.31 (-0.5 to 1.1)</td>
<td>-0.05 (-0.88 to 0.79)</td>
<td>0.73 (-0.2 to 1.6)</td>
<td>0.0 (-0.8 to 0.8)</td>
</tr>
<tr>
<td>Pain</td>
<td>-0.49 (-1.27 to 0.35)</td>
<td>0.18 (-0.66 to 1.0)</td>
<td>-0.48 (-1.35 to 0.42)</td>
<td>0.03 (-0.77 to 0.83)</td>
</tr>
</tbody>
</table>

TENS = Transcutaneous electrical nerve stimulation, CAR = Central Activation Ratio, MVIC = Maximal voluntary isometric contraction. Negative effect sizes for CAR and MVIC indicate a deficit in the effect, while negative effects for pain indicate beneficial effects.
effect in this population. Additionally the lack of a significant group difference may represent insufficient statistical power. This sample used in the current study was derived from a previous study\textsuperscript{21} that found strong immediate involved leg CAR effects of TENS in a similar population. While strong effects may be anticipated following a TENS intervention for quadriceps CAR in the involved leg, effects of the same magnitude may not be plausible in the uninvolved leg.

Quadriceps CAR contributes to muscle strength and functional abilities in people with TFOA.\textsuperscript{17} Quadriceps MVIC in the TENS groups was significantly higher than the placebo group across time, while no differences were found between any other group means. This finding was likely due to the placebo group having a lower baseline normalized MVIC than the TENS group. There was a tendency for the MVIC in the TENS group to increase, resulting in moderate effect sizes at 2-weeks, the placebo mean slightly decreased over those time periods (Tables 2 and 3). It is most interesting to note that at 2-weeks, the TENS group showed a moderate positive effect size indicative of increased MVIC, while control and placebo effects remained small despite the equivalent exercise programs (Table 3). It is not clear why these moderate TENS effects found at 2-weeks decreased at 4 weeks, yet it may be indicative of some accommodation to the TENS stimulus. Additionally, greater standard deviations were found for contralateral quadriceps CAR at 4-weeks compared to 2-weeks. This increased variability in the CAR outcome measure may have acted to decrease the effect size point measure. Again, there should be caution in the interpretation of these strong to moderate effect sizes as all the confidence intervals do cross 0, indicating the lack of assurance in these effect size point measures.

DISCUSSION
Quadriceps activation failure has been reported following a variety of different knee joint injuries.\textsuperscript{7} This activation failure has been commonly reported in people with tibiofemoral osteoarthritis\textsuperscript{1,2,16,17} and has been found to be a moderator of physical function.\textsuperscript{4} Bilateral deficits in quadriceps activation have been reported following unilateral joint injury, which has been hypothesized to be caused by central nervous system modulation.\textsuperscript{27} The current study was the first to evaluate if a disinhibitory treatment on the involved extremity would alter quadriceps activation on the uninvolved extremity. The working hypothesis was that quadriceps activation in the uninvolved leg would increase in the group that received TENS in conjunction with therapeutic exercise to the involved leg. However, no difference in quadriceps CAR between groups following the intervention was found.

The mean quadriceps CAR in the involved leg was lower than in the uninvolved leg at baseline (Table 1 and 2). Researchers\textsuperscript{9,24,25} have suggested that a CAR of less than .95 indicates significant quadriceps inhibition. All group means for uninvolved CAR were between .84 and .86, suggesting bilateral inhibition in our sample (Table 2). Although CAR was not statistically different between the TENS, placebo and control groups, strong and moderate CAR effect sizes were found between pre and posttest measures for the TENS group at 2 and 4 weeks respectively (Table 3). It should also be noted that no or small negative effects were found for the control and placebo groups at both post tests, suggesting that practical CAR effects in the uninvolved limb were non-existent for these groups (Table 3). The presence of these strong to moderate TENS effect sizes is clouded by the corresponding 95% confidence that all cross 0. Although the magnitude of the effect size point measures are strong, the corresponding wide confidence intervals may provide further evidence to the insignificant statistical results indicating the lack of a contralateral
that the time points with the largest effects for CAR (2-weeks) do not correspond with the time points for the largest effects for decreased pain (4-weeks), no definitive conclusions about the nature of the relationship between CAR and pain can be made. While it is reasonable that increased effects in CAR could lead to moderate effects for pain, much of this is speculative and lacks substantive evidence. Further evidence is needed to not only determine the effects of disinhibition on pain in the involved leg, but also to determine if disinhibition directly effects pain in the uninvolved side. It should be noted that the visual analog pain score means in the uninvolved leg were all \( \leq 10.1 \) out of a possible 100 at baseline. This is likely because the uninvolved knee was measured, meaning this knee was either asymptomatic or at the very least self-reported to be more functional when compared to the involved leg. Therefore the low pain scores at baseline represent the relative absence of pain, which may be the reason that a change in pain status was not found.

Change in uninvolved quadriceps CAR was found to explain a significant, but small amount of change in CAR (19%) and MVIC (23%) of the involved leg at 4-weeks. Although significant differences were not found between groups, these significant correlations in conjunction with moderate to strong effect sizes for uninvolved CAR in the TENS group may be evidence for continued research in the effects of bilateral disinhibition. Additionally, this data suggests that increased CAR and MVIC in the uninvolved leg is responsible for approximately 20% of the increase in those measures on the involved quadriceps. Clinically, this may be evidence to suggest that effort spent directing disinhibiting the uninvolved leg may have positive benefits on activation and strength outcomes on the involved side. While treatment of the uninvolved extremity will likely increase therapy cost, further evidence should be gathered to determine if bilateral disinhibitory interventions on therapeutic outcomes are cost and time efficient.

Previous authors have concluded that the neural drive is immediately increased during the active administration of sensory TENS current, and that TENS immediately diminishes the excitatory effect upon removal. Current theories suggest that TENS provides increased afferent stimuli interpreted by the central nervous system as excitatory resulting in the facilitation of inhibited motor neuron pools. All CAR, MVIC and pain testing in the current study was performed when the TENS current was interrupted, suggesting that all moderate to strong effects the uninvolved limb were sustained in the absence of an active excitatory TENS current on the involved knee. The moderate to strong effects and significant correlations found by the current authors suggest that these possible bilateral central nervous system adaptations may occur due to plastic changes in neural networks that were functional in the absence of the electrical current. While the exact neurophysiology behind bilateral inhibition and disinhibition remains undescribed, this data may offer promising evidence to suggest that these deficits may be affected by use of TENS in conjunction with therapeutic exercise.

The current study is not without limitations. Although the previous study, from which the subjects for this experiment were gleaned reported significant differences in the involved leg of patients following TENS with similar sample sizes, this investigation failed to find significant differences. This is likely a product of low statistical power stemming from a sample size that was relatively small in order to demonstrate statistical differences with effects that were lower than previous data. Although moderate to strong effect sizes were reported for CAR, MVIC and pain in the TENS group, 95% confidence intervals all crossed zero, suggesting that definitive conclusions regarding the existence of similar effects for these outcomes will be present in subsequent samples (Table 3). Classification by the current authors of the uninvolved limb was based substantially on the fact that there was less perceived dysfunction in this side, which does not mean that osteoarthritis was not present on this side as well. Previous authors have suggested that seemingly low levels of osteoarthritis not easily distinguishable with radiographs may have effects on decreasing CAR. This means that quadriceps CAR deficits in the uninvolved leg may have actually been a product of osteoarthritis in that leg as well as any bilateral effects that may have been caused by the involved leg. Nevertheless, this experiment was the first to evaluate the possible effects of bilateral disinhibition following unilateral intervention, which has produced
interesting data suggesting further investigation into the benefits and mechanisms contributing to this possible phenomenon.

In conclusion, there were no significant differences between groups for uninvolved quadriceps CAR or pain, while MVICs in the TENS group remained increased compared to the placebo group throughout the 4-week intervention. Moderate to strong uninvolved CAR, MVIC and pain effect sizes were found in the TENS group, while all corresponding 95% confidence intervals crossed 0. Significant correlations suggested that changes in uninvolved CAR and MVIC at 4-weeks explain 19% and 23% of the variance in the change of those measures in the involved leg.

REFERENCES


ABSTRACT

Study Design: Clinical Measurement, Correlation, Reliability

Objectives: To assess the relationship between the Single Leg Balance (SLB), modified Balance Error Scoring System (mBESS), and modified Star Excursion Balance (mSEBT) tests and secondarily to assess inter-rater and test-retest reliability of these tests.

Background: Ankle sprains often result in chronic instability and dysfunction. Several clinical tests assess postural deficits as a potential cause of this dysfunction; however, limited information exists pertaining to the relationship that these tests have with one another.

Methods: Two independent examiners measured the performance of 34 healthy participants completing the SLB Test, mBESS test, and mSEBT at two different time periods. The relationship between tests was assessed using the Pearson Correlation and Fisher's Exact Tests. Inter-rater and test-retest reliability were assessed using the intraclass correlation coefficient (ICC) and Kappa statistics.

Results: A significant correlation ($r = -0.35$) was observed between the mSEBT and the mBESS. Fisher's Exact Test showed a significant association between the SLB Test and mBESS ($P = .048$), but no association between the SLB and mSEBT ($P = 1.000$). Inter-rater reliability was excellent for the mSEBT and fair for the mBESS (ICCs of .91 and .61 respectively). Excellent agreement was observed between raters for the SLB test ($\kappa = 1.00$). Test-retest reliability was excellent for the mSEBT (ICC = 0.98) and fair for the mBESS (ICC = 0.74). There was poor test-retest agreement for the SLB test ($\kappa = .211$).

Conclusion: There was a significant relationship observed between the SLB Test, mBESS test, and mSEBT; however, strength of association measures showed limited overlap between these tests. This suggests that these tests are interrelated but may not assess equal components of postural stability.

Key Words: reliability, postural stability, star excursion balance test, single leg balance, balance error scoring system

ORIGINAL RESEARCH
ASSOCIATIONS BETWEEN THREE CLINICAL ASSESSMENT TOOLS FOR POSTURAL STABILITY
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This research was conducted at the United States Military Academy, Arvin Cadet Physical Therapy Clinic, Physical Therapy Department, West Point, NY. No funding support was received for this research study. At the time of the research, Dr. Clark was completing a post-professional sports physical therapy residency under the mentorship of Dr. Gerber as well as completing his DScPT in Physical Therapy from Baylor University, Waco, TX. The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the US Air Force, US Army, the Department of Defense, or the United States Government.

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INTRODUCTION

Ankle sprains are the most common traumatic injury in sports, with injury rates among athletes between 12-33%.1, 17, 22, 24, 25 Athletes who participate in sports that require sudden stopping, planting, and cutting such as football, soccer, and basketball are especially vulnerable to these injuries.2, 4, 10, 18, 19, 26 Full recovery after an ankle sprain is often time consuming and incomplete. Because ankle sprains account for 16-23% of all sport injury time lost, and athletes commonly report lingering dysfunction, it is important to determine reliable methods to identify individuals at risk to ankle sprains and to develop preventative initiatives to reduce their risk.31, 17

One risk factor associated with an increased incidence of ankle sprains is impaired postural stability.3, 6, 9, 29-31, 34 Researchers commonly report that there is an established relationship between postural stability deficits and chronic ankle instability5-8, 30, 32. To identify those who have an increased risk for ankle sprains (both first time and recurrent), devices such as stabilometry have been effectively used to objectively assess postural stability.18 The disadvantages with stabilometry are that it is expensive, time consuming, and not readily available to most clinicians. In contrast, several clinical measures of postural stability such as the Single Leg Balance (SLB) test, Balance Error Scoring System (BESS), and the modified Star Excursion Balance Test (mSEBT) are inexpensive, quick to administer, and typically accessible in clinical and field settings. Poor performance on these tests may also prove to be an indicator that a person has an increased risk of a future ankle sprain.

The development, utilization, and understanding of these measures of postural stability are in the beginning stages. Of the commonly used clinical and field measures of postural stability, the mSEBT appears to be the “gold standard”. However, while the mSEBT has shown consistently strong inter-rater and intra-rater reliability, it is more time consuming than the SLB and BESS.13-16, 20, 23 The latter assessments are relatively new tests for predicting lower extremity injury and have demonstrated varying degrees of reliability in assessing impaired postural stability.7, 21, 27, 28, 33

The primary purpose of this study was to assess the relationship between the SLB, a modified version of the BESS (mBESS), and mSEBT tests, utilizing the mSEBT as the criterion measure for identifying postural deficits. A secondary purpose of this study was to assess inter-rater and test-retest reliability of these 3 tests. If the SLB and mBESS tests demonstrate strong relationships with the mSEBT and are reliable to perform, clinicians may opt for a simpler, less resource intensive measure to assess postural stability.

METHODS

Subjects

Thirty-four volunteers from the United States Military Academy, West Point, New York enrolled in the study. They were included if they were generally healthy and between the ages of 17 and 25. Participants were excluded from the study if they reported any history of lower extremity or head injury (concussion) within the previous 12 weeks, a history of ankle sprain within the past twelve months, any inner ear disturbance at the time of testing, or a history of prior ankle surgery. Participants were also excluded if they were currently in a boxing course or boxing club due to an increased risk of concussion and potential loss to follow-up testing (Figure 1). This study was reviewed and approved by the Institutional Review Board at Keller Army Hospital (West Point, NY) with secondary review by the U.S. Army Clinical Investigation Regulatory Office (Ft. Sam Houston, TX). All participants read and signed an informed consent and HIPPA addendum form prior to enrollment and the rights of all participants were protected throughout the study.

Procedures

Participants were randomly assigned a sequence in which they were to perform the SLB Test, mBESS test, and mSEBT (Figure 1). Each participant was given a brief orientation and demonstration of the testing procedures. Testing was performed in a semi-private area with the participant barefoot, wearing loose fitting shorts and a t-shirt. The subject’s dominant leg (one he or she kicked with) was always tested first. Participants were allowed to practice each test prior to performance to minimize learning effect, and they received a minimum of a one minute rest period between each test. One practice attempt was allowed for the SLB and mBESS tests,
and a minimum of one and maximum of 6 practices for the mSEBT as per the protocol of Hertel et al.\textsuperscript{15}

To examine inter-rater reliability, two examiners performed assessments independently at the same time during the balance tests. To examine test-retest reliability, the subjects were scheduled for re-testing approximately 15-28 days (mean = 23 days) after the initial test to minimize a potential learning effect\textsuperscript{33}. Participants were again randomly assigned a sequence of balance testing for the second assessment.

**Postural Stability Testing**

The SLB test was performed in accordance with the Trojan protocol.\textsuperscript{28} Participants stood on one foot with the contralateral knee slightly bent and not touching the weight bearing leg, hips level to the ground, and eyes open and fixed on a spot marked on the wall. Once participants had obtained their balance, they closed their eyes for 10 seconds. Investigators noted if the participant's legs touched each other, the ipsilateral foot moved on the floor, the contralateral foot touched down, the eyes opened, or the arms moved from their start position. If the participant had a positive test (failed to remain balanced) during the first trial, a second trial was performed, with the results of the second trial counting for analysis.

Docherty et al\textsuperscript{7} noted in their BESS study on athletes that there was no statistical difference during the test between subjects with and without functional ankle instability in the double leg stance positions and the tandem stance on a firm surface. Due to these results, a modified BESS (mBESS) test was derived by this facility for this study in attempts of creating a clinical test that would be appropriate for testing athletes with impaired postural stability. The mBESS test was performed by having participants stand unsupported with their eyes closed under 6 conditions: 3 different stances (single-limb dominant, single-limb non-dominant, and tandem with...
dominant foot in front) on 2 different surfaces (a firm surface {floor} and a foam surface). The foam surface conditions were performed on a block of 3-inch thick Aeromat medium-density foam. For each condition, participants were instructed to place their hands on their hips, close their eyes, and remain as motionless as possible for 20 seconds. Participants were instructed to return to the test position as quickly as possible if they were to lose their balance. During each trial, researchers recorded one error for each time they observed any of the following: 1) lifting hands off iliac crests; 2) opening eyes; 3) stepping, stumbling, or falling; 4) moving the hip into more than 30 degrees of flexion or abduction; 5) lifting the forefoot or heel; 6) remaining out of the testing position for more than five seconds. During pilot testing, the two testers used a goniometer to determine the 30 degree hip flexion limit. Subsequently, the testers used a marking on the wall for a visual reference to determine if subjects had moved into greater than 30 degrees of hip flexion. The total number of errors for each test condition was scored individually and also summed to produce the participant's total mBESS score.

The mSEBT was performed as described by Plisky et al.23 Participants stood with their foot centered at the intersection of 3 lines (Figure 2) with the most distal aspect of their stance limb great toe at the 10 cm line. Participants maintained single-leg stance while reaching with the contralateral leg to touch as far as possible along the chosen line. All participants were given the same instructions: to maintain foot-flat stance during the test maneuver. If the foot moved at any time during the test, the test was stopped, the foot repositioned, and the test repeated. They touched the furthest point possible on the line with the most distal part of their foot as lightly as possible so that the reach leg did not provide any significant support in the maintenance of upright posture. The examiners marked the point touched along the line and then manually measured the grid. The participant repeated this three times on each line, and completed all three lines for a total of 9 reaches. The distance reached was averaged and recorded for each direction and also summed to produce the participant's total mSEBT score. In addition, data was normalized as recommended by Gribble et al12 by dividing the average reach distance by the participant's leg length, and then multiplying the value by 100.

**Statistical Analysis**

Descriptive statistics for categorical and continuous variables were calculated to summarize the data. Tests for outliers and assumptions for utilization of the statistical tests were performed. Separate one-way ANOVAs were performed to assess for significant differences in the total mBESS and mSEBT scores. The independent variable evaluated was whether subjects passed or failed the SLB test. Plots of the means were performed to demonstrate the relationships between each of these tests, and the SLB. Pearson Correlation studies were performed between continuous data of the mSEBT and mBESS. To allow for correlational analysis between the SLB, the data for the mSEBT and mBESS was collapsed to nominal, dichotomous data. This was done by determining if an individual would be considered “positive” or “negative” based on the performance on the test. A “positive” for these tests was operationally defined as poor postural stability. For the mSEBT, a participant was considered “positive” if he or she demonstrated a dominant to non-dominant difference of ≥4 cm.23 For the mBESS, a participant was considered “positive” if the number of balance errors during the test was greater than one standard deviation above the mean.
Similarly, subjects who failed the SLB also had significantly lower mSEBT total scores, which also represent poorer postural stability ($P = .025$) compared to those who passed the SLB test (Table 1). A plot of the means of the mBESS and mSEBT by outcome on the SLB is presented in Figure 3. A significant ($P < .05$) correlation ($r = -0.35$) was observed between the mSEBT and the mBESS (Figure 4). Subjects with poorer postural stability scores on the mSEBT also seemed to have poorer postural stability scores on the mBESS. Strength of association measures suggest that the total mBESS score accounts for approximately 12% of the variability in the mSEBT score ($r^2 = 0.12$). When scores from the mBESS and mSEBT were collapsed, Fisher’s Exact Test revealed a significant association between the SLB Test and the mBESS ($P = .048$), but no association was observed between the SLB and mSEBT ($P = 1.00$).

### RESULTS

Thirty-four participants (20 males, 14 females; mean ages of 20.9 ± 1.92 and 20.43 ± 2.21 years respectively) enrolled and completed the study. Twelve of the 34 participants failed to maintain balance on the SLB during one of the 2 testing periods. Of those twelve, 4 failed only during the first testing period, 5 failed only during the second testing period, and 3 failed during both testing periods. The mean number of total errors on the mBESS was 16.5 ± 7.6. Most errors occurred while testing the non-dominant leg on the foam surface (4.5 ± 2.0 errors) while the fewest errors occurred while testing tandem on firm surface (0.8 ± 0.9 errors). Five participants demonstrated a dominant to non-dominant difference of >4 cm on the mSEBT. The duration for each test (from explanation to completion) was approximately 78 seconds for the SLB, 273 seconds for the mBESS, and 311 seconds for the mSEBT. The authors of this paper are confident that no learning effect was observed between trials, as subject performance did not improve during the second trials.

### Associations between tests

Subjects who failed the SLB test made significantly more errors when performing the mBESS ($P = .005$), suggesting that they had poorer postural stability when compared to those who passed the SLB. Similarly, subjects who failed the SLB also had significantly lower mSEBT total scores, which also represent poorer postural stability ($P = .025$) compared to those who passed the SLB test (Table 1). A plot of the means of the mBESS and mSEBT by outcome on the SLB is presented in Figure 3. A significant ($P < .05$) correlation ($r = -0.35$) was observed between the mSEBT and the mBESS (Figure 4). Subjects with poorer postural stability scores on the mSEBT also seemed to have poorer postural stability scores on the mBESS. Strength of association measures suggest that the total mBESS score accounts for approximately 12% of the variability in the mSEBT score ($r^2 = 0.12$). When scores from the mBESS and mSEBT were collapsed, Fisher’s Exact Test revealed a significant association between the SLB Test and the mBESS ($P = .048$), but no association was observed between the SLB and mSEBT ($P = 1.00$).

### Reliability

Inter-rater reliability was excellent for the mSEBT and fair for the mBESS (ICC$^s$ of 0.91 and 0.61 respectively).
(2,1). Excellent agreement was observed between raters for the SLB test ($\kappa = 1.00$) (2,k). Test-retest reliability was excellent for the mSEBT (ICC = 0.98) (2,1) and fair for the mBESS (ICC = 0.74) (2,1). There was poor test-retest agreement for the SLB test ($\kappa = 0.21$) (2,k).

**DISCUSSION**

The primary finding of this study was that while there was a significant relationship between several clinical postural stability tests, the strength of association was limited. This suggests that these tests may be interrelated but may not assess similar components of postural stability. Secondarily, of these three clinical measures of postural stability, the combination of inter-rater and test-retest reliability is highest for the mSEBT.

Because the SLB, mBESS, and mSEBT are all measures of postural stability, the authors of this study hypothesized there would be a strong relationship between the tests. However, the results do not support this hypothesis. Despite the similarities between the three tests, there is one fundamental difference between these tests. The SLB and the mBESS are static tests, whereas the mSEBT is a dynamic, functional test. This could explain why the authors found a significant association between the 2 static tests, but not between the SLB and the mSEBT. Additionally, while there was a significant correlation between the mBESS and mSEBT, the relationship was not as strong as we would have anticipated ($r = -0.35$). This suggests that only 12% of the variability in scores of one test can be explained by the results of the other test. Practically, this means that while these tests are interrelated it appears they do not measure the same component of postural stability. The SLB test is a simple, static pass/fail test that may be strongly influenced by external factors that provided only nominal data. As the subject is only provided a maximum of two opportunities to test, little room for error is available for a “bad test”. The mBESS is also a static test, but provides a greater amount of continuous data and tests six postural positions. If a participant has difficulty in a single position, the poor performance may be less apparent in their overall score if they perform well on the remaining tests. The mSEBT is a dynamic functional test that averages the performance of three trials in each direction, diminishing the potential effect of a single outlying (poor) performance.

The SLB test is a clinically alluring measure of postural stability as it is the most efficient, least
study, however, to demonstrate both excellent inter-rater and test/retest reliability. These findings are consistent with others who have studied reliability using the mSEBT. In addition, the mSEBT has been shown extensively to be sensitive in identifying postural stability deficits. While it would be appealing to use a more efficient and easier test, ultimately, the results of the current study support that in the clinical setting where stabilometry is not accessible, the mSEBT should continue to be considered as the best available criterion measure to assess postural stability. However, as discussed above, it should be noted that the mBESS and mSEBT may assess different components of postural stability (i.e., static versus dynamic postural stability). Further investigation is needed to determine how these measures may complement each other in assessing static and dynamic aspects of postural stability as well as determining the potential role of these assessments in injury screening and prevention initiatives.

Some limitations associated with this study should be noted. This study was performed on a relatively small sample size, only using healthy individuals. Stronger relationships between the postural stability tests may have been observed if both injured and uninjured participants were tested. It is possible that a ceiling effect was observed in this study as these tests simply may not have been sensitive enough to discriminate postural stability differences in healthy individuals. Perhaps the results would have been different for example in those with ankle pathology. Therefore, future research looking at a larger sample that includes both injured and uninjured individuals would be beneficial. Additionally, no controls were instituted for a variety of external factors that could affect performance between testing periods. Several factors such as fatigue, time of day, activities prior to the testing, amount of sleep the night prior, concentration, and a multitude of other factors could have affected the ability of participants to perform on these postural stability tests. While it is possible that controlling such factors could have improved test/retest reliability, these factors realistically are not controlled for in most clinical settings. Given the variety of external factors that could have negatively affected participants' performance over time, the excellent test/retest reliability demonstrated by the

Compared to the SLB and mBESS tests, the mSEBT takes the most time to administer and requires the most equipment. It was the only measure in this

Compared to the SLB, the mBESS test takes longer to administer and requires some equipment (i.e., foam surface pad). A potential advantage, however, is that the mBESS provides more detailed information than simply a pass/fail score that the SLB provides. The mBESS demonstrated fair inter-rater reliability (ICC = .61) and test/retest reliability (ICC = .74) suggesting that the test appears to be a more reliable objective test when compared to the SLB, but in this study showed lower intratester reliability than those reported in previous studies on the original BESS. However, for an athletic population, this version of the mBESS needs further refinement and testing to improve its test/retest reliability, but it appears to have the potential to be a useful objective test in identifying athletes with impaired static postural stability. Further research continues to be important to determine the clinical applicability of the SLB and mBESS tests.

Compared to the SLB and mBESS tests, the mSEBT takes the most time to administer and requires the most equipment. It was the only measure in this

Some limitations associated with this study should be noted. This study was performed on a relatively small sample size, only using healthy individuals. Stronger relationships between the postural stability tests may have been observed if both injured and uninjured participants were tested. It is possible that a ceiling effect was observed in this study as these tests simply may not have been sensitive enough to discriminate postural stability differences in healthy individuals. Perhaps the results would have been different for example in those with ankle pathology. Therefore, future research looking at a larger sample that includes both injured and uninjured individuals would be beneficial. Additionally, no controls were instituted for a variety of external factors that could affect performance between testing periods. Several factors such as fatigue, time of day, activities prior to the testing, amount of sleep the night prior, concentration, and a multitude of other factors could have affected the ability of participants to perform on these postural stability tests. While it is possible that controlling such factors could have improved test/retest reliability, these factors realistically are not controlled for in most clinical settings. Given the variety of external factors that could have negatively affected participants' performance over time, the excellent test/retest reliability demonstrated by the
mSEBT provides further evidence of its reliability as a clinical postural stability test.

**CONCLUSION**

There was a statistically significant relationship observed between the mBESS and mSEBT, but the strength of relationship was weak. Additionally, there was a significant association observed between the SLB and the mBESS. This suggests that these tests are interrelated but that they may not assess equal components of postural stability. While there was perfect ($\kappa = 1.00$) interrater reliability with the SLB test, this test demonstrated poor test/retest reliability significantly impacting its clinical utility. The mBESS demonstrated fair interrater reliability and fair test/retest reliability. The mSEBT demonstrated excellent interrater and test/retest reliability. Further research to determine the best applications and utility for each of these clinical postural tests is warranted.

**REFERENCES**


ABSTRACT

Background. Although rare in occurrence, a dorsal dislocation of the 1st metatarsophalangeal (MTP) joint has been successfully treated using surgical and/or non-operative treatment. No descriptions of conservative intervention following a dorsal dislocation of the MTP joint in an athlete participating in a high contact sport are present in the literature.

Objectives. The purpose of this case report is to describe the intervention and clinical reasoning during the rehabilitative process of a collegiate football player diagnosed with a 1st MTP joint dorsal dislocation. The plan of care and return to play criteria used for this athlete are presented.

Case Description. The case involved a 19-year-old male Division IA football player, who suffered a traumatic dorsal dislocation of the 1st MTP joint during practice. The dislocation was initially treated on-site by closed reduction. Non-operative management included immobilization, therapeutic exercises, non-steroidal anti-inflammatories, manual treatment, modalities, prophylactic athletic taping, gait training, and a sport specific progression program for full return to Division IA football.

Outcomes. Discharge from physical therapy occurred after six weeks of treatment. At discharge, no significant deviations existed during running, burst, and agility related drills. At a six-month follow-up, the patient reported full return to all football activities including contact drills without restrictions.

Discussion. This case describes an effective six-week rehabilitation intervention for a collegiate football player who sustained a traumatic great toe dorsal dislocation. Further study is suggested to evaluate the intervention strategies and timeframe for return to contact sports.

Key Words. dislocation, metatarsophalangeal joint, football

CORRESPONDENCE

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INTRODUCTION

A dorsal dislocation of the 1st metatarsophalangeal (MTP) joint is a rare occurrence in sport. Motor vehicle accidents are the most common cause of injury, followed by both falls from heights and athletic injuries. The mechanism of injury occurs from a high energy force acting from distal to proximal with forced hyperextension at the MTP joint. Consistent physical impairments with this injury include fixed plantar dislocation of the 1st metatarsal head, dorsal extension of the proximal phalanx, shortening of the 1st ray, edema, and loss of great toe function.

A Type I MTP dislocation, under the classification scheme designed by Jahss, is a dislocation of the hallux with no disruption of the sesamoid mass. (Tables 1 and 2). The incidence and prevalence of this dislocation in sport is unknown. Jahss reported an extremely low incidence of 0.008%, in non-sport cases, which equals two traumatic dislocations in 25,000 patients. Successes of both operative and non-operative management are presently unclear in the literature as functional outcomes have not been consistently reported. Rather, authors have commonly reported range of motion and pain as outcome measures.

Only two cases have been reported in sport of 1st MTP dorsal dislocations. Wolf et al reported a non-contact injury, resulting from a decelerated landing in basketball, treated surgically after repeated attempts at closed reduction failed. Two months after the injury, the athlete was asymptomatic and had full range of motion of the great toe. Whether the patient received a rehabilitation program or if the individual returned to sport was not noted. De Palma et al reported a dorsal dislocation, non-contact injury, in a football player who struck his great toe against the playing surface. The 1st MTP was immobilized for four weeks, and the patient was non-weight-bearing (NWB) with functional exercises beginning four weeks post-injury. Details of the treatment plan were not described, although the athlete returned to sport successfully. Other than these reports, the literature does not provide clear long term outcomes, or a treatment plan with return to play guidelines for an athlete who sustains a MTP dislocation in a contact sport. Information on a progressive treatment program and timeframe for immobilization may help prevent unnecessary lost training time for the athlete.

The Hallux Metatarsophalangeal-Interphalangeal Scale developed by The American Orthopaedic Foot and Ankle Society (AOFAS) is a clinical numerical rating system describing function, pain, and alignment of the great toe. One hundred total points are possible in a patient who is pain free and has normal metatarsophalangeal (MTP) and interphalangeal (IP) joint ROM, an absence of MTP or IP joint instability, good alignment, no recreational or daily activity limitations, and no limitations in footwear.

| Table 1. Jahss Classification System of 1st Metatarsophalangeal Joint Dislocations. |
|---------------------------------|------------------------------------------------------------------------------------------------|
| Type I                          | Dorsal dislocation with no disruption of the sesamoid mass, usually irreducible on closed reduction attempts |
| Type IIA                       | Dorsal dislocation with a rupture of the intersesamoidal ligament resulting in a wide separation of the sesamoids on the metatarsal head allowing an easier reduction to occur |
| Type IIB                       | Dorsal dislocation with a medial sesamoidal transverse fracture, usually reducible |
| Type III                       | Dorsal dislocation with the sesamoids maintaining the same anatomical position with complete ruptures of the conjoint tendons and intact sesamoids and volar plate |

| Table 2. Type IIC addition to the Jahss Classification System, as proposed by Copeland and Kanat. |
|---------------------------------|------------------------------------------------------------------------------------------------|
| Type IIC                      | Dorsal dislocation with a medial sesamoid transverse fracture, usually reducible |
and laterally. These mechanics will be referenced throughout this report as a dorsal dislocation of the first metatarsophalangeal joint. The patient reported pain, numbness, and tingling at the 1st MTP joint radiating distally to the distal phalanx. He was unable to rise from a quadruped position. The athletic trainer on site performed a closed reduction by applying a longitudinal distraction to the joint. The patient was immediately referred to the team physician in the clinic who ordered radiographs to rule out a fracture and also ordered an MRI to check for the extent of the damage to the plantar plate. Following the closed reduction, radiographs taken the same day were unremarkable with no signs of a fracture. The sesamoid bones were intact with minor sesamoid widening. No sign of sesamoidal proximal migration was present. Magnetic resonance (MR) imaging was performed with multiple sagittal T1 and gradient images to check for soft tissue abnormalities. The radiologist noted a stretch in the plantar aspect of the capsule in the 1st MTP joint with a small amount of fluid present. A small focus of intra articular low signal intensity has an appearance suggesting the presence of air in the joint space. In the setting of

points), and scoring involves both objective and subjective factors. The highest score in each of the three categories demonstrates no presence of pain, no functional limitations, and a well aligned hallux. The lowest score in each of the three categories demonstrates severe pain, severe functional limitations, and a poor symptomatic hallux alignment.

The purpose of this case report is to describe the intervention, including the return to play of a collegiate football player diagnosed with a 1st MTP joint dorsal dislocation as well as the clinical reasoning process utilized by both the physical therapist and athletic trainer to formulate the plan for intervention. The patient's plan of care included therapeutic exercises, joint mobilizations, prophylactic athletic taping, non-steroidal anti-inflammatories, manual treatment, modalities, neuromuscular training, gait, and sports-specific drills for full return to Division IA football. To the authors' knowledge, no descriptions of conservative interventions following a dorsal dislocation of the MTP joint for return to high-contact sport are present in the literature.

CASE DESCRIPTION

The patient was a 19-year-old male Division IA football player (tight end) who fell after a tackle during practice, and a 302-pound linebacker landed on his right foot. The patient suffered a traumatic dorsal dislocation of the 1st metatarsophalangeal (MTP) joint. He described that his forefoot was in contact with the ground, with the great toe in extension when another player sat on his heel during a tackle (Figure 1) (Video Clip Re-Enactment available on the NAJSPT website). He was a well-conditioned, 230 pound sophomore lineman, 6 feet, 3 inches in height. He had successfully completed pre-season football and finished one in-season football game. His primary goal was to return to in-season football. Recreational activities included Olympic lifting, exercising on the elliptical, and golfing.

EXAMINATION

On-Site Initial Assessment

The initial examination was performed by the staff athletic trainer on-site at practice within seconds after the injury occurred. On observation, the 1st MTP joint was positioned in a varus deformity with the proximal phalanx being displaced both dorsally and laterally. These mechanics will be referenced throughout this report as a dorsal dislocation of the first metatarsophalangeal joint. The patient reported pain, numbness, and tingling at the 1st MTP joint radiating distally to the distal phalanx. He was unable to rise from a quadruped position. The athletic trainer on site performed a closed reduction by applying a longitudinal distraction to the joint. The patient was immediately referred to the team physician in the clinic who ordered radiographs to rule out a fracture and also ordered an MRI to check for the extent of the damage to the plantar plate.

Following the closed reduction, radiographs taken the same day were unremarkable with no signs of a fracture. The sesamoid bones were intact with minor sesamoid widening. No sign of sesamoidal proximal migration was present. Magnetic resonance (MR) imaging was performed with multiple sagittal T1 and gradient images to check for soft tissue abnormalities. The radiologist noted a stretch in the plantar aspect of the capsule in the 1st MTP joint with a small amount of fluid present. A small focus of intra articular low signal intensity has an appearance suggesting the presence of air in the joint space. In the setting of

Figure 1. Graphic Representation of the Mechanism of Injury
recent trauma, intra articular air implies joint capsule disruption and joint trauma following dislocation. Both the flexor hallucis longus and flexor hallucis brevis muscles appeared normal. Based on the MR imaging, the patient's injury most closely matched a Type I MTP joint dislocation according to the Jahss Classification System. A Type I dislocation is a dorsal dislocation without disruption of the sesamoid mass. It should be noted that this patient suffered a stretch of the plantar aspect of the 1st MTP joint, which will later be discussed as this patient may not be classified as a true, uncomplicated, Type I dislocation. In conclusion, both clinical examination and the MR imaging suggested that the patient sustained a right 1st MTP dorsal dislocation. The team physician determined surgery was not indicated, and the subject was therefore referred for conservative management.

INTERVENTION

The patient was treated three times a week by the physical therapist and three times a week by the staff athletic trainer over a six-week period in 3 phases: Phase I: Early Protection, Phase II: Activity Progression, and Phase III: Return to Sport (Table 3). The goal of the treatment was to regain full strength, range of motion, joint mobility, proprioception, gait, and agility for return to collegiate football. No previous interventions or return-to-play criteria were cited in the literature, therefore, the authors of this case report have provided an intervention strategy with a rationale for each phase that was used throughout the rehabilitation of this patient (Table 4).

PHASE I: Early Protection (Days 1-3)

Examination

The patient was seen shortly after injury by the physical therapist from athletic rehabilitation services. During a brief exam, visual inspection revealed severe ecchymosis and diffuse soft tissue edema surrounding the 1st MTP joint. The exam was limited secondary to pain. On the American Orthopaedic Foot and Ankle Society (AOFAS) Hallux Metatarsophalangeal-Interphalangeal Scale (100 possible points), the patient scored 55 points at the time of initial injury. Low scores represent severe limitations and higher scores represent least limitations in the given categories. The patient received low scores in the function subcategories of activity limitations, footwear requirements, MTP joint motion, and metatarsophalangeal joint-interphalangeal joint stability.

The patient reported a verbal rating pain scale of 3/10 only during gait. During examination on day three, observation revealed continued edema, ecchymosis, and limited 1st MTP joint flexion and extension. Passive range of motion (PROM) of the right 1st MTP joint extension was 0-42 degrees and flexion 0-40 degrees. Passive range of motion of the non-injured side was 0-60 degrees of extension and 0-50 flexion. Manual muscle testing revealed flexor digitorum longus, peroneals, and tibialis posterior strength of 4-/5 with pain upon testing, extensor hallucis longus, extensor digitorum longus, and gluteus medius muscle strength of 4-/5 and pain free; flexor hallucis longus strength of 4/5 and pain free; tibialis anterior, gastrocnemius, and soleus muscles, 5/5 and pain free.

Intervention

The clinical goals during Phase I were to protect the joint and allow for tissue regeneration and collagen remodeling. Other goals included control of pain, edema, and inflammation. Instructions for gait included a non weight-bearing (NWB) status utilizing crutches with a short leg walking boot. Although evidence does not support the use of modalities for pain and edema control, modalities were applied over the R foot surrounding 1st MTP joint area with the goals of controlling both pain and edema control, per institutional policy. This included pulsed ultrasound 2MHz (Dynatron 150 Combo, Isokinetics, Inc.) at 50% for 8 minutes, contrast bath (alternating cold and warm bath for 15 minutes total), electrical stimulation using Premodulated Interferential current for 15 minutes, and cryotherapy (cold pack 20 minutes). Clinical judgment was used to determine modality use and parameters as there is lack of supportive research for modality application for any of the chosen modalities as applied after a first MTP joint dorsal dislocation. A compression wrap was administered and therapeutic exercises were restricted during the first two days to help reduce edema and pain. Edema reduction is important in order to help improve joint motion needed for gait in later rehabilitation. During heel off, the hallux reaches near end range extension during the gait cycle. The team physician restricted the athlete from participation in any football activities.
Table 3. The 3 Phases of Intervention Used For a Collegiate Athlete after sustaining 1st MTP Dorsal Dislocation.

<table>
<thead>
<tr>
<th>PHASE I</th>
<th>PHASE II</th>
<th>PHASE III</th>
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<tbody>
<tr>
<td>Early Protection</td>
<td>Activity Progression</td>
<td>Return To Sport</td>
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<tr>
<td>Days 1 to 3</td>
<td>Day 3 to 4 Weeks</td>
<td>Weeks 5 to 6</td>
</tr>
<tr>
<td>NWB, short leg walking boot</td>
<td>PWBAT (day 4-8)</td>
<td>Orthotics/shank</td>
</tr>
<tr>
<td>AROM</td>
<td>Discontinue walking boot (2 wks)</td>
<td>Great Toe Taping</td>
</tr>
<tr>
<td>Great Toe Flexion and Extension</td>
<td>Orthotics/shank (2 wks)</td>
<td>Gait Training</td>
</tr>
<tr>
<td>Ankle Circles</td>
<td>Great Toe Taping</td>
<td>Jogging sagittal plane</td>
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<tr>
<td>Ankle Pumps</td>
<td>(limiting extension and abduction)</td>
<td>Jogging multiplanar</td>
</tr>
<tr>
<td>BAPS Board (anterior-posterior, medial-lateral, clockwise and counterclockwise)</td>
<td>Long sit hamstring stretch, kneeling hip flexor stretch, piriformis stretch</td>
<td>Agility: -running routes - passing/driving blocks: non-contact. - &gt;With sandband-&gt; with sled-&gt; live contact</td>
</tr>
<tr>
<td>Towel Toe Crunches</td>
<td>Longsit and Standing Gastroc</td>
<td>Return to practice non-contact prior to live contact</td>
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<tr>
<td>Marble Toe Pick Ups</td>
<td>Stretch, Great Toe flexion and extension stretching</td>
<td><strong>Full Return to Practice</strong></td>
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<tr>
<td>Gait Training</td>
<td>4 way SLR with cuff weights (ie hip flexion, adduction, extension abduction)</td>
<td>Electrical Stimulation premodulation 15 minutes as needed.</td>
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<tr>
<td>Ultrasound, 2 MHz 8 min, pulsed 50%</td>
<td>Ankle Theraband 4 way</td>
<td>Cold Pack 20 minutes</td>
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<tr>
<td>Electrical Stimulation premodulation 15 minutes</td>
<td>Ankle Isolator Exerciser SL balance with balance pad</td>
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<tr>
<td>Contrast Bath (alternating cold/warm whirlpool) 15 minutes</td>
<td>Clamshell</td>
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<tr>
<td>Cold Pack 20 minutes</td>
<td>Step up (forward and sideways)</td>
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<tr>
<td>Compression Wrap</td>
<td>Lunges (clock)</td>
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<td></td>
<td>Leg press with resistance cords</td>
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<td></td>
<td>Leg curl</td>
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<td></td>
<td>Leg extension</td>
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<td></td>
<td>Walking program</td>
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<td></td>
<td>Sidelying leg press (shuttle)</td>
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<td>Hip extension in standing with pulleys</td>
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<td></td>
<td>Forward and lateral step ups</td>
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<td>Heel raises</td>
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<td>Core program (ie bridges on ball with sagittal flexion and oblique curl ups)</td>
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Table 4. The Clinical Decision Making Table: A summary of the examination findings, clinical reasoning, and intervention utilized throughout the Case Report.

<table>
<thead>
<tr>
<th>TIMEFRAME</th>
<th>EXAMINATION FINDINGS</th>
<th>CLINICAL DECISION MAKING (Goals)</th>
<th>INTERVENTION (Refer to text for dosage details)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days 1-3</td>
<td>Edema &amp; ecchymosis at 1st MTP PROM R MTP flexion and extension limited</td>
<td>Restore AROM and PROM at MTP for normalized gait</td>
<td>AROM: great toe flexion and extension, ankle circles, ankle pumps, BAPS board (anterior-posterior, medial-lateral, and clockwise-counter-clockwise), towel toe crunches, marble toe pick ups. Compression wrap. Modalities: Contrast bath, US, electrical stimulation, cold pack.</td>
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<tr>
<td>Day 9</td>
<td>Decreased WB during stance phase of gait. Decreased R tibial advancement also during stance phase</td>
<td>Remodeling and strengthening of connective tissues</td>
<td>progressed previous exercises by adjusting resistance loads according to the patients repetition endurance and symptom response. Modalities: continue same modalities. Single leg balancing on balance pad progressing with to without shoe support. Ankle isolator (plate loaded resisted plantar flexion, dorsiflexion, inversion and eversion), sidelying leg press on shuttle (resistance cords). Walking program; gait instructions emphasizing equal WB, and introduce MTP ext in late stance. Core Program (bridges on gym ball with trunk sagittal flexion, oblique curl ups, and lower trunk curl ups). Discontinued contrast bath and continued all remaining modalities. Orthotics/shank placed in shoe. Great toe athletic taping limiting abduction and extension.</td>
</tr>
<tr>
<td>2 Weeks</td>
<td>No pain reported during gait when using orthotics and tape. Limited MTP extension during gait as expected (due to orthotics w/shank). Decreased strength R posterior tibialis and gluteus medius. 4-5</td>
<td>Restore gait mechanics Continue to protect MTP after walking boot is discontinued</td>
<td>Sagittal plane jogging progressing to multiplanta joggning with zig zag patterns. Agility: progression of running route non-contact-&gt;hitting blocking sarsbag-&gt;hitting sled-&gt;live contact passing/driving block. Modalities: Electrical Stimulation and cold pack. Orthotics/Shank remains in shoe Taping. Progress number of consecutive plays during practice (initial 5-6 consecutive plays during practice). Modalities: Electrical Stimulation and cold pack. Orthotics/Shank remains in shoe Taping.</td>
</tr>
<tr>
<td>6 Weeks</td>
<td>Normal running gait in sagittal and multiplanta directions. Mild stiffness reported at R 1st MTP during performance of 90 degree cutting maneuver at full speed. PROM R 1st MTP extension normal relative to uninvolved side</td>
<td>Progress contact drills for sports specific conditioning Prepare for full return to sport</td>
<td>Sagittal plane jogging progressing to multiplanta joggning with zig zag patterns. Agility: progression of running route non-contact-&gt;hitting blocking sarsbag-&gt;hitting sled-&gt;live contact passing/driving block. Modalities: Electrical Stimulation and cold pack. Orthotics/Shank remains in shoe Taping. Progress number of consecutive plays during practice (initial 5-6 consecutive plays during practice). Modalities: Electrical Stimulation and cold pack. Orthotics/Shank remains in shoe Taping.</td>
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On day 3, the goals were advanced to address the restoration of the MTP joint active range of motion (AROM) needed for gait. Normal active range of motion MTP joint extension during the gait cycle is 0-60 degrees. Therefore, active range of motion exercises were prescribed to help the patient restore joint motion needed for gait. Land and pool exercises were performed consisting of AROM of great toe flexion and extension, ankle dorsiflexion/plantarflexion, inversion and eversion. Additional land exercises included baps board (anterior-posterior, medial-lateral, and ankle circles both clockwise and counterclockwise), towel crunches with toes and marble pick ups.

PHASE II: Activity Progression (Day 3 – week 4)

Examination (days 3-8)
During days four to eight, the examination findings revealed a Trendelenburg gait with left gluteus medius muscle weakness, decreased strength at the right flexor hallucis longus (FHL), extensor hallucis longus (EHL) and posterior tibialis muscles, rated 4-/5. His previous medical records indicated that the Trendelenburg gait was present from a previous left ankle surgery. Ecchymosis and edema were still present about the MTP. The patient reported complaints of right great toe pain rated 3-4/10 with gait and 0/10 at rest.

Intervention
The clinical goals were to restore gait, strength, and balance. Other factors included initiating proprioception and tendon training, progressing to strengthening. Tendon training refers to high repetition activities with low resistance loads. Tendon training prepares the patient to withstand stresses to the tendons that occur during gait. The MTP joint approaches an extension load during heel off placing stress on the hallux flexor tendons. Therefore, tendon training plays an important role in preparing the foot for repetitive motions that gait demands. The patient was advised to continue wearing a short leg walking boot, continue partial weight-bearing as tolerated with crutches from days four to eight, gradually tapering off crutch use during this time frame.

Phase II Activity Progression intervention lasted from day three to week four. Lower extremity exercises were prescribed for the ankle, calf, and foot intrinsic muscles. Isotonic ankle exercises were prescribed using a plate loaded platform ankle device called “The Ankle Isolator”, which allowed for resisted plantar flexion, dorsiflexion, inversion, and eversion. Also, hip strengthening and balance exercise progression were incorporated over this time period. This included isotonic leg extension, leg curl, clams shells (resisted hip abduction with external rotation), prone hip extension and sidelying leg raises. The patient performed 2 sets of 20 repetitions increasing the resistance loads and sets progressively based on his symptoms and endurance ability. The repetitions were progressed to 12-15 repetitions with the weights adjusted accordingly based on the patient’s ability to safely withstand the new loads. Balance training included single leg balancing with a balance pad, starting with 30 seconds with shoe support and increasing the seconds based on patient tolerance. The shoe was removed for balance training when the patient discontinued the walking boot at 2 weeks. Gait training was continued.

Examination (days 9-10)
On day nine, the patient was FWB and completely discontinued the use of crutches. Decreased WB during the loading phase and decreased tibial advancement during the midstance phase was revealed during visual analysis of gait. Visual inspection 10 days post-injury revealed presence of ecchymosis although it had decreased by 30% since initial exam. The surface area of the ecchymosis remained the same. Soft tissue edema was present located at the plantar, dorsal, and medial surfaces along the 1st metatarsal joint and surrounding tissues. The patient reported tenderness to palpation along the 1st MTP joint line on all surfaces. Negative tenderness to palpation along the intertarsal joint and the remaining lesser MTP joints were noted. Valgus and varus tests of the 1st MTP joint at 0 and 30 degrees were negative. Static positional hallux valgus in the resting position was unremarkable. Further exam of the ankle ligaments was unremarkable for pain or ligamentous instability. Strength testing performed using methods described by Daniels and Worthingham revealed decreased strength in the right posterior tibialis, right FHL, and right EHL muscles, rated 4-/5. The plantar dorsal translation test, also known as the vertical stress test, of the 1st MTP joint was negative with a good endpoint.
This test is used to check for a tear of the plantar plate.

**Intervention**

The clinical goals were progressed to address remodeling and strengthening of the connective tissue. The functional demands of walking require good strength of contractile and non-contractile tissues about the great toe. Therefore, strengthening exercises were prescribed and progressed to help meet the muscular and soft tissue demands of gait as previously discussed. Gait training progression emphasized a gradual return of MTP joint extension during late stance. Gentle great toe flexion and extension passive range of motion was gradually introduced during this time frame. Weight bearing loads on the forefoot were progressed during the loading phase until weight bearing was symmetrical. Intervention included gait training and a strengthening progression program. The exercises performed during days 9-10 were isotonic leg extension, leg curl, clam shells (hip abduction with external rotation), prone hip extension and sidelying leg raises. The patient performed 2 sets of 15-20 repetitions increasing the resistance loads and sets progressively based on his symptoms and endurance ability. The repetitions were progressed to 12-15 repetitions with the weights adjusted accordingly based on the patient's ability to safely withstand the new loads. Single leg balancing with shoe support was performed increasing the time duration based on patient ability and tolerance. The patient's gait was progressed to full weightbearing without crutches as he demonstrated a stable, unimpaired gait.

**Examination (2 weeks)**

At two weeks, the patient was prescribed custom fitted orthotics with a semi-rigid carbon shank and polyurethane cover for protection of the MTP joint. Visual analysis of gait revealed limited right MTP joint extension as expected since he was wearing the orthotics during the exam for protection. Decreased stance time during stance phase was present on the injured lower extremity. Manual muscle testing revealed right posterior tibialis and gluteus medius weakness strength of 4-/5. The AOFAS score at two weeks post-injury was 74 points. The subcategories of function in which the patient did not receive total points were activity limitations, footwear requirements, and MTP joint motion. Passive range of motion testing of the right 1st MTP joint revealed 0-34 degrees extension and 0-45 degrees flexion. Manual muscle testing revealed FHL, EHL, extensor digitorum longus (EDL), tibialis posterior, and gluteus medius muscles, all 4-/5 and pain free; flexor digitorum longus (FDL) muscle, 4/5; peroneal muscles, 4+/5; Tibialis anterior, gastrocnemius, and soleus muscles, 5/5. Although manual muscle testing strength grades did not improve at 2 weeks, his ability to achieve full weightbearing with a stable gait and no loss of balance demonstrated increased function.

**Intervention**

The clinical goals were to restore gait mechanics and continue to protect the MTP joint. Presence of pain and joint edema inhibits normal muscle contraction which could interfere with gait. Protecting the MTP joint by use of the orthotic assisted in preventing further pain and joint edema during tissue healing. During a trial of both great toe taping and the orthotics with an incorporated shank, the patient denied any pain during gait. The purpose of the great toe taping was to limit the patient's metatarsophalangeal joint extension and intermetatarsal joint abduction for joint capsule protection during collagen remodeling. One-inch width athletic tape was used to apply anchors at the distal great toe and midfoot. Next, longitudinal strips and spica strips were applied to both anchors restricting excessive great toe hyperextension and intermetatarsal joint abduction. Next ½ circumferential closing strips were applied. Lastly, the midfoot, forefoot and great toe were fully closed with lightplast.

The patient was advised by the team physician to discontinue the walking boot and begin to utilize the orthotics in a supportive shoe in order to continue to protect the joint. The great toe taping was also added as a supplement to the orthotic as the patient reported it made him feel better. The rehabilitation prescription included strengthening using leg press with resistance cords (ie Shuttle™), single leg stance hip extension with pulleys, forward and lateral step ups, step downs, and lunges in clock positions. The patient performed 3 sets of 20 repetitions, progressing to 3 sets of 12-15 repetitions with adjusted resistance based on his symptoms and his endurance to withstand increased loads and decreased repetitions.
He also performed leg press and heel raises on his uninjured lower extremity starting at 3 sets of 12-15 repetitions. Airex™ single leg balance training was performed in order to improve both balance and proprioception, progressing from 30 to 60 seconds for 3-6 repetitions (wearing shoe support). The patient’s gait continued to be monitored with instruction emphasizing equal weight bearing and gradually progressing MTP joint extension motion during late stance as mentioned previously. The patient also performed core exercises in a bridge position on a Swiss ball (sagittal plane flexion, oblique sit ups). He also performed lower trunk curl ups without the ball. At 3 weeks post injury the patient began walking on the treadmill for 10 minutes practicing his gait pattern. The duration was gradually increased over the course of treatment.

**PHASE III: Return to Sport (Weeks 5-6)**

**Examination (week 5)**

At 5 weeks, the patient continued to be pain-free with a walking gait. A trial of jogging gait was unremarkable for any deviation of gait biomechanics, balance, or presence of pain. The examination revealed restored right 1st MTP PROM relative to the uninvolved side. The patient had adequate strength assessed functionally by demonstration of a normal gait cycle although great toe flexor and extensor muscles and peroneals still demonstrated strength of 4/5 at 6 weeks. (See Table 4). Single-leg (SL) balance testing with perturbations was unremarkable demonstrated by no loss of balance or pain being reported during 60-90 seconds holds. The patient's uninvolved side tested at 90 seconds. Intermittent mild edema was present at the great toe.

**Intervention**

The clinical goals included introducing sports specific activities that were position-specific for a tight end. The activity demanded of a tight-end offensive lineman includes multi-planar running, cutting, tackling, striking, and blocking. Strength, explosive power, speed, agility, are all needed throughout a running gait cycle for a tight end. The activities of a lineman/tight end are primarily anaerobic. Therefore, the intervention prescribed included a striking/blocking progression where the patient explodes from a stance phase hitting a sand bag, then a sled, then live contact play during practice which progressed throughout weeks five to six. The running progression program incorporated sagittal plane, then multi-planar running with zigzag patterns. Noncontact football routes both with and without live practice were included (Figure 2). For all phase III activities, the intensity and duration were increased over time and as the patient tolerated. The use of electrical stimulation tapered off as great toe swelling diminished and a cold pack continued to be administered as needed during the presence of edema. Noncontact practice was resumed at week five.

**Examination (week 6)**

At six weeks, examination revealed a normal running gait both in sagittal and multi-planar directions. Passive range of motion of the right 1st MTP joint was normal relative to the uninvolved side in both extension and flexion. Mild stiffness was reported during gait at the right 1st MTP joint while cutting at a 90 degree angle at full speed. The AOFAS score at six weeks was 95 points. The patient scored 5 points out of a total possible 10 points in the subcategory of foot-wear requirements as he was still wearing his shoe orthotic. Passive range of motion testing of the right 1st MTP joint revealed 0-30 degrees extension and 0-50 degrees flexion. Manual muscle testing of the flexor hallicus longus, flexor digitorum longus, extensor hallicus longus, and extensor digitorum longus muscles, demonstrated continued strength of 4/5; peroneal and gluteus medius muscles, 4+/5; tibialis posterior muscle, 5-/5; tibialis anterior, gastrocnemius, and soleus muscles, 5/5.

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**Figure 2. Sport Specific Functional Progression for Tight End.**
plays to not exceed five to seven plays. Over time, participation in plays slowly increased. He continued his rehabilitation program independently and was taped throughout the remainder of the season. Electrical stimulation with ice (ie 15 minutes, premodulation) continued to be used as needed for edema control.

OUTCOMES

On the American Orthopaedic Foot and Ankle Society (AOFAS) Hallux Metatarsophalangeal-Interphalangeal Scale\(^8\) (100 possible points), the patient scored 55 points at the time of initial injury, 74 points at two weeks, and 95 points at six weeks (time of discharge) (Figure 3). At six months, he scored 100 points demonstrating no disability associated with his previous left foot pain (Table 5). A summary of the strength outcomes as measured by manual muscle testing per procedures of Daniels and Worthingham\(^12\) is provided in (Table 6), and the passive range of motion outcomes as measured per procedures of Norkin and White\(^14\) are provided in Figure 4.

DISCUSSION

To the knowledge of the authors, no other case report exists detailing the results of conservative

**Table 5.** The American Orthopaedic Foot and Ankle Society (AOFAS) Hallux Metatarsophalangeal-Interphalangeal Scale\(^8\) (100 possible points).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Initial Eval</th>
<th>2 weeks</th>
<th>Discharge 6 weeks</th>
<th>6 months</th>
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<tr>
<td>AOFAS</td>
<td>55</td>
<td>74</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>Pain Scale</td>
<td>3/10 w/gait</td>
<td>0/10 rest and gait</td>
<td>0/10 rest and gait</td>
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</tbody>
</table>

**Table 6.** Strength testing\(^12\) of the right lower extremity measured at four time intervals

<table>
<thead>
<tr>
<th>STRENGTH: R LE</th>
<th>Initial Eval</th>
<th>2 weeks</th>
<th>Discharge 6 weeks</th>
<th>6 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexor Hallicus Longus (FHL)</td>
<td>4/5</td>
<td>4/5</td>
<td>4/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Flexor Digitorum Longus (FDL)</td>
<td>4/5 w/pain</td>
<td>4/5</td>
<td>4/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Extensor Hallicus Longus (EHL)</td>
<td>4/5</td>
<td>4/5</td>
<td>4/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Extensor Digitorum Longus (EDL)</td>
<td>4/5</td>
<td>4/5</td>
<td>4/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Posterior Tibialis</td>
<td>4/5 w/pain</td>
<td>4+5</td>
<td>4+5</td>
<td>5+5</td>
</tr>
<tr>
<td>Peroneals</td>
<td>4/5 w/pain</td>
<td>4+5</td>
<td>4+5</td>
<td>5+5</td>
</tr>
<tr>
<td>Gluteus Medius</td>
<td>4/5</td>
<td>4+5</td>
<td>4+5</td>
<td>4+5</td>
</tr>
</tbody>
</table>

R= Right
LE= Lower extremity
w/pain= Testing elicited pain
management following a 1st MTP dorsal dislocation for a patient returning to in-season, Division IA football. The clinical goals were centered around the desire to minimize the time lost in-season and to maximize the effectiveness of the rehabilitation. Clinical interventions included modalities, strengthening, joint range of motion exercises, proprioceptive exercises, gait, and agility drills during a progressive rehabilitation program. Following a successful rehabilitation program, the patient returned to football in six weeks time. Only two sport-related cases of a 1st MTP dislocation have been reported in the literature, one of which reported successful return to sport. 4,5 Neither case clearly discussed long-term outcomes nor a treatment plan with return to play guidelines for sport. De Palma et al 4 reported a 1st MTP dorsal dislocation with immobilization for four weeks non-weightbearing and functional exercise, which began after four weeks time. This patient was immobilized for two weeks in the walking boot and was partial weight-bearing with crutches at day four. The walking boot was removed for his rehabilitation sessions. He began range of motion exercises on day three. These findings indicate it is possible for an athlete to follow a conservative rehabilitation approach and successfully return to football.

This patient was classified as a Jahss Type I dislocation. As previously mentioned, the Jahss classification 1 refers to Type I being a dislocated hallux with no sesamoid mass disruption. Type II is a rupture in the intersesamoidal ligament with widened sesamoids. The authors believe this patient likely suffered a Type I+ dorsal dislocation as the hallux dislocated while the intersesamoidal ligament did not rupture but suffered a partial stretch. This description, to our knowledge, has not yet been noted in the literature. Also noted in the literature is that Type I dislocations are often irreducible and require surgery. 1 However, this case demonstrates that closed reduction was possible, and was followed by an excellent outcome.

At four weeks and 5 days post injury, the patient was able to return to light jogging non-contact football practice. At six months follow-up, this patient was able to demonstrate all football activities including multiplanar running, cutting, tackling, and striking without difficulty. Seven months post injury, he continued full participation in spring season football and was without disability. The patient’s only complaint was mild soreness at the right 1st MTP joint during 90-degree cutting maneuvers, which he reported did not interfere with his full speed running ability. Gait examined during cutting appeared unremarkable both with and without his custom orthotics.

The authors discussed whether or not the patient may have benefitted from removing the walking boot several days earlier should another athlete present with this type of injury. This patient progressed and performed so well using implemented treatment program in the described time frames that a shorter period of immobilization might be considered. It must be acknowledged however, that the long term outcomes of such an injury managed with shorter immobilization timeframe is unknown.

A MTP joint ROM impairment can affect the gait cycle. Normal ROM of the 1st MTP joint is 30 degrees flexion and 90 degrees extension. 60 degrees extension is required for the gait cycle. When heel rise and toe off occur in the stance phase, the hallux and lesser toes reach end-range maximum extension. 11 If the MTP joint is prevented from fully extending, the heel-off to toe-off phase is impaired which can alter running, jogging, and cutting mechanics. An athlete with impaired great toe ROM can be functionally disabled, thereby limiting sports performance.

Passive range of motion extension at the 1st MTP joint did not progressively increase over the course of rehabilitation as did flexion range of motion. The subject’s passive range of motion at initial evaluation was 0-42 degrees whereas at six months, it was 0-31 degrees. Although this reported range of motion does not reach the value for “normal,” the patient’s gait function was good and he reported minimal

**Figure 4. MTP Joint Range of Motion, in degrees.**
symptoms, so we did not push his range. Perhaps he was performing within a range that he only functionally needed, which may have allowed him to return to running without difficulty. The cause of the decrease in range of motion could have been from scar tissue developing during the foot protection progression from the walking boot, to shoes with custom orthotics, with additional taping as needed. The amount of foot protection provided was based on both the stage of his injury, the quality of the patient’s gait, and any presence of symptoms.

Notice should be taken that this proposed Type I+ dislocation was treated immediately on the field with closed reduction. Rehabilitation with early protection began on day one of injury without a time delay. The time between injury occurrence and treatment has been noted to affect the ability for the dislocation to maintain closed reduction. Similar Type I dislocations amongst athletes treated with early intervention, proper immobilization and rehabilitation can possibly result in a successful return to sport.

**SUMMARY**

First MTP joint dorsal dislocations are rare in the general population and are even a rarer occurrence in sport. No evidence exists in the literature regarding rehabilitation and return to play guidelines for a football player. In this case study, the patient who was treated with closed reduction with no sign of complications returned to in-season Division IA college football six weeks post-injury following conservative management with minimal disability (AOFAS) and a normalized running gait. Further study is necessary to evaluate a wide variety of possible intervention strategies and timeframe for return to contact sports with greater numbers of patients who sustain a MTP dislocation.

**ACKNOWLEDGEMENTS**

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**REFERENCES**

CASE REPORT
CONSERVATIVE REHABILITATION OF SCIATIC NERVE INJURY FOLLOWING HAMSTRING TEAR

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Paul Reuteman, PT, MHS, OCS, ATC²

ABSTRACT

Study Design: Resident's case report

Background: There have been only a few case reports in the literature mentioning sciatic nerve injury following a hamstring tear. In previous cases surgical intervention was performed to debride scar tissue around the sciatic nerve with the goal of full return to function for the patient.

Objectives: The purpose of this case report is to describe the conservative interventions that allowed for recovery from a hamstring tear with sciatic nerve involvement.

Case Description: The subject was a 53 year old female who developed foot drop and weakness in the common fibular nerve distribution following a grade 3 hamstring injury sustained during Nordic skiing. Nerve function and strength gradually returned over the course of several months of conservative rehabilitation which included neural gliding and strengthening exercises.

Outcomes: At 18 months post injury, the subject had returned to 95% of full sport function and 98% of full function with activities of daily living, as rated by the Hip Outcome Scale, and had full strength with manual muscle testing. Isokinetic testing revealed strength deficits of 11–23% in knee flexion peak torque at 60 degrees/second and 180 degrees/second respectively.

Discussion: Sciatic nerve injury is a rare, but important potential consequence of severe hamstring strains. Clinicians should be cognizant of the potential injury to the nerve tissue following hamstring strains, so they may be dealt with in a prompt and appropriate manner. The use of neural gliding may be worth considering for a prophylactic effect following hamstring strains.

Key Words: foot drop, nerve glide, sciatic nerve, hamstring strain

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Note: Case occurred while primary author was a resident in the sports physical therapy residency program at Gundersen Lutheran Sports Medicine in Onalaska, WI.

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INTRODUCTION

Hamstring tears are common sports injuries that often require physical therapy intervention. In a literature review of hamstring avulsion injuries that required surgical intervention, it was found that skiing was one of the most common mechanisms of injury.\textsuperscript{1,2} Water skiing accounts for almost 30\% of hamstring tears in Australia\textsuperscript{1} and Nordic skiing has been reported to account for 40\% of tears in Finland.\textsuperscript{2}

A rare sequela associated with a hamstring tear is an injury to the sciatic nerve due to the proximity of the anatomical structures. There have been a few reports of sciatic nerve involvement with hamstring injuries in the literature.\textsuperscript{3-8} Each of these cases involved at least a partial avulsion/tear of the proximal hamstrings. In all of these cases, surgical intervention was the only reported intervention that alleviated the subjects’ symptoms related to the nerve injury. The surgery was performed to attempt to release scar tissue from around the sciatic nerve. In one case where symptoms did not improve, surgery was performed to reattach the hamstring but no debridement of scar tissue was performed.\textsuperscript{7} At the time of the writing of this case report, there were no documented cases detailing the successful conservative rehabilitation of a complete hamstring tear with sciatic nerve involvement. The purpose of this report is to present the details of a case where a patient recovered from a hamstring tear with sciatic nerve involvement with conservative care as the only intervention. The patient described in this case report gave written informed consent for the description of her case and use of diagnostic images (magnetic resonance imaging \{MRI\} and photograph of leg) to be published.

CASE DESCRIPTION

Subjective – Initial Evaluation

The patient was a 53 year old female who was referred to physical therapy with a diagnosis of a Grade III (complete) tear of the medial hamstring following a cross country ski accident involving a fall. During the fall, she reported that the right lower extremity slid forward while her trunk moved forward creating hyper flexion at the right hip. Ecchymosis was noted by the patient extending from her posterior thigh down to her ankle two days following the injury (Figure 1). Medical care was sought five days following the injury at which time she was diagnosed with a grade 3 hamstring tear and referred to physical therapy.

At the initial physical therapy visit, the patient reported that she had been icing and elevating her leg since her injury. She used an ACE wrap for compression around her thigh to allow her to walk and stand for longer periods of time. Walking for extended periods of time was difficult. While ascending stairs, she had to use a step to step gait pattern, relying on the left lower extremity. She also reported that knee extension with hip flexion (as in sitting), caused distal hamstring pain. As a result, she kept her knee flexed a majority of the time. The patient reported pain rated at 4/10 at rest, experienced mostly in her calf. With movements such as getting in and out of a car, pain was rated at 8/10. She denied any previous leg or back injuries. Her occupation as a teacher required her to stand for long periods of time and she found this to be difficult to perform due to pain. On the Hip Outcome Scale (HOS) she rated her function at 60\% for activities of daily living (ADLs) and 0\% for sports activities. The HOS asks patients to rate their ability to perform different daily activities. A copy of

Figure 1. Ecchymosis in posterior leg 2 days following injury.
the HOS is included in Appendix 1. The patient had the most difficulty with squatting, putting on sock/shoes, rolling over in bed, pivoting on her involved leg, heavy work (pushing/pulling/carrying), and recreational activities. The HOS has been suggested in an unpublished report, to have excellent test-retest reliability for the HOS ADL subscale (ICC = 0.96) and moderate to strong correlations ($r = 0.69-0.74$) with the physical function subscale and physical summary score of the SF-36. Her main goals were to return to ascending and descending stairs, walking, running, biking, and cross country skiing.

**Objective - Initial Examination**

Upon observation during the initial examination, ecchymosis was present from the patient's posterior thigh, medial greater than lateral, down to the medial calf (Figure 1). She ambulated with an antalgic gait due to pain with bearing weight on the right leg and decreased extension of her right knee during stance phase. Due to decreased excursion of the right leg, heel strike was decreased. With palpation, there was a firm mass noted in the mid third of the semitendinosus and semimembranosus muscle bellies. She displayed tenderness from the posterior thigh extending down the entire right lower leg with Grade I pitting edema in the lower leg. Active range of motion (AROM) of the right knee via a heel slide while the patient was supine was measured at $0^\circ-4^\circ-95^\circ$ compared to $0^\circ-133^\circ$ degrees on the left knee. Circumferential measurements revealed that the right leg was 2.5 cm greater at 15 cm distal to the knee joint line, 3 cm greater at the knee joint line, 2 cm greater at 10 cm proximal to the knee joint line, and 2 cm greater at 20 cm proximal to the knee joint line. Due to patient discomfort, strength testing was not performed during the initial examination.

It was determined that the patient had signs and symptoms consistent with the medical diagnosis of a grade III hamstring tear. Her primary impairments included limited range of motion (ROM), lower extremity edema, and gait deviations. Strength was also likely impaired, but due to pain levels formal muscle testing was not performed.

Intervention provided at the initial visit consisted of retrograde massage in the right leg and instruction in the performance of a home exercise program. The home program consisted of ankle pumps with the lower extremity elevated to decrease lower extremity swelling, quad sets to facilitate muscle activation in the right lower extremity, very gentle passive hamstring stretching in the longsitting position via use of a towel, and education regarding the importance of continued use of ice and compression.

**Visits 2-5**

Over the next 4 visits lower extremity stretching and strengthening was progressed (refer to Table 1). Closed chain exercises consisting of single limb balance work to improve proprioception and trunk stability were added based upon the work by Sherry and Best that showed improved outcomes when agility and trunk stabilization exercises were incorporated into a rehabilitation program for hamstring strains. Retrograde massage was continued to help decrease swelling and light cross friction massage was added to assist in tissue remodeling in the medial hamstring muscles.

The patient displayed steady progress over these visits. Gait returned to normal with normal excursion and heel strike, AROM was restored to full as compared to the other leg and the patient was able to return to previous work activities without restrictions.

**Visits 6-10**

At visit number 6, the patient reported slipping at home three days prior in a mechanism similar to her original injury. This slip occurred 28 days after her initial cross country skiing injury. Following this slip, she reported some soreness in the original injury location, however, she returned to pain-free walking by the time she presented to the clinic for the sixth visit.

By the seventh visit, she reported her lateral hamstring tendons “felt different” and she had increased soreness in her posterior knee and calf. Upon inspection, there was decreased tone in the gastrocnemius and biceps femoris compared to the uninjured side. By the eighth visit, her gait was altered in that she advanced her right leg more quickly than her left and she noted increased pain in her medial gastrocnemius muscle. During ambulation, she felt decreased control of her leg. By the ninth visit, 17 days after
touch was intact and symmetrical and deep tendon reflexes were rated at 2+.

Based on these findings, it was determined the patient had sustained an injury to the sciatic nerve, particularly affecting the common fibular nerve division. She was provided active dorsiflexion and eversion exercises in attempts to maintain ankle range of motion and was also advised to continue with her hamstring strengthening exercises as able. Due to her neurologic injury, she was instructed to use her opposite leg to assist in performing prone knee flexion for hamstring strengthening. Due to the progressive change in her status, she was referred back to her physician for further diagnostic testing.

### Diagnostic tests

Following evaluation by her physician, further diagnostic tests were ordered. An electromyographic
Table 2. Objective measurements taken throughout course of treatment.

<table>
<thead>
<tr>
<th>Week</th>
<th>HOS (ADL/Sport)</th>
<th>DF MMT</th>
<th>PF MMT</th>
<th>Eversion MMT</th>
<th>Inversion MMT</th>
<th>DF AROM</th>
<th>DF PROM</th>
<th>HS MMT</th>
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<tbody>
<tr>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recheck, 18 months post injury</td>
<td>98/95</td>
<td>5/5</td>
<td>5/5</td>
<td>5/5</td>
<td>5/5</td>
<td>10</td>
<td>10</td>
<td>5/5</td>
<td>4/5 (B)</td>
<td></td>
</tr>
</tbody>
</table>

Key: HOS = Hip Outcome Scale, ADL = Activities of Daily Living, DF = dorsiflexion, MMT = Manual Muscle Test, PF = plantarflexion, HS = hamstring, EHL = Extensor Hallucis Longus, EDL = Extensor Digitorum Longus

(EMG) analysis revealed severe denervation of the biceps femoris and tibialis anterior, and to a lesser extent denervation to the semitendinosus. It was concluded that an injury to the branches off of the tibial and common fibular portion of the sciatic nerve had occurred. Neurapraxia of the common fibular nerve or posterior tibial nerve was not reported.

Based on these results, an MRI was recommended. The MRI revealed abnormal signal intensity throughout all 3 muscles of the hamstring, with a focus of extremely low signal intensity extending a length of 12 cm from the common insertion on the ischium (Figure 2). These findings suggested a subacute to chronic tear with fibrosis and muscular atrophy. The MRI findings did not reveal any damage to the sciatic nerve. Based on these results, it was decided to focus PT interventions upon improving sciatic nerve mobility in order to prevent the fibrosis within the muscle from affecting the nerve.

Re-initiation of PT

Visit 12

Following her examination, the patient’s primary physician recommended continued conservative
Following the reexamination, the plan of care was modified to include sciatic nerve glides (both in the clinic and at home) in a seated position with the knee extended and moving the ankle into dorsiflexion and plantarflexion. Butler proposes that healing tissues need movement to assist healing and neural glides were added with this goal in mind. Neuro-muscular electrical stimulation (NMES) was included to facilitate muscular recruitment of the peroneals and tibialis anterior during active dorsiflexion and eversion performed by the patient. This was added because the EMG revealed severe, but not complete denervation and the treating therapist thought that NMES might help with muscular recruitment. She was encouraged to continue with her active knee and ankle motion at home.

Visits 13-34 (weeks 12-33 of treatment)
Over the next 22 weeks, lower extremity strengthening and functional demands were progressed, as shown in Table 1. Progression of exercises was based on patient strength and ability to perform exercises, with focus on proprioceptive training and isolated muscle strengthening activities. Emphasis was placed on hamstring and dorsiflexion strengthening in both open chain and in closed chain through use of single leg stability exercises. Her home program continued to emphasize nerve glides, as previously instructed, as well as active dorsiflexion and knee flexion. Electrical stimulation of the muscles responsible for dorsiflexion was eliminated from the treatment program after visit 16 as the electrical stimulation was not improving the quality of muscle contraction over volitional contraction of the muscles alone. Electrical stimulation was attempted on the hamstrings in order to attempt to improve muscle recruitment, but a contraction could not be elicited within the amount of current tolerated by the patient.

An initial Biodex™ isokinetic test for knee flexion/extension was performed at visit 19 (Table 3). Analysis of peak torque revealed a 62.1% flexion strength deficit at 60 degrees per second and a 49.9% flexion strength deficit at 180 degrees per second when compared to unaffected leg.

By the time of re-examination at week 19, the patient was ambulating without restrictions and with a normal pattern during ADLs, however she continued to

management to address the patient’s impairments. Dependant upon how the patient responded to conservative care, the need for neurolization surgery was to be determined. She was re-examined by the physical therapist after a 35 day break from conservative treatment. This re-examination was performed 89 days after the original skiing injury. During the time off from therapy, she continued to perform active range of motion exercises for ankle dorsiflexion and eversion, as well as prone knee flexion, (which she acquired the ability to perform independently during this time). She maintained a very light stretching program for the hamstrings, performed in the long sitting position, using 30 sec holds.

Upon examination, muscle recruitment of the biceps femoris had increased from the last visit prior to her diagnostic testing, but was still greatly reduced when compared to the unaffected side. She was able to perform a prone hamstring curl without assistance and strength was rated at 3/5. Additional objective measures are noted in Table 2. The HOS was not issued again at this visit.

![Figure 2. MRI image of hamstring. There is diffuse abnormal signal intensity throughout the semimembranosus, semitendinosus, and biceps femoris tendons with a focus of extremely low signal intensity proximally. This suggests a subacute to chronic tear with fibrosis and diffuse muscle atrophy.](image)
involved extremity. She did not ski the winter following her injury due to fear of reinjury.

Objectively, on the HOS, the patient had improved from 65% to 98% for ADLs and 0% to 95% for sport activities when compared to her initial visit in physical therapy. Manual muscle testing was equal between legs, rated at 5/5 for all previously tested muscles, except great toe extension which was graded at a 4/5 bilaterally. Slump-sit testing revealed slightly more tension on the left leg versus the right but motion was equal. Hamstring flexibility via a passive straight leg raise was 86 degrees of hip flexion on the right and 92 degrees on the left.

Analysis of peak torque via Biodex™ testing (Table 3) revealed a deficit in knee flexion strength of 11.5% at 60 deg/sec and 23.3% at 180 deg/sec when compared to the uninvolved leg. This demonstrates a 50.6 percentage point improvement at 60 deg/sec and 26.6 percentage point improvement at 180 deg/sec when comparing the initial testing session to last testing session. The deficit that remains at the faster testing speed illustrates the patient's incomplete recovery, particularly for higher level activities that require faster speeds of muscular contraction, such as those required in athletics. Table 3 shows the progression of strength via Biodex™ testing over the 6 tests that were performed during the course of PT.

**DISCUSSION**

In this case, a patient was able to return to near full function following a sciatic nerve injury that occurred following a grade 3 hamstring tear. This is the first

<table>
<thead>
<tr>
<th>Week</th>
<th>Peak torque in Newton/meters at 60 deg/sec</th>
<th>% Deficit from left leg</th>
<th>Peak torque in Newton/meters at 180 deg/sec</th>
<th>% Deficit from left leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>15.1</td>
<td>62.1</td>
<td>13.1</td>
<td>49.9</td>
</tr>
<tr>
<td>23</td>
<td>34.5</td>
<td>35.5</td>
<td>27.4</td>
<td>29.6</td>
</tr>
<tr>
<td>32</td>
<td>31.1</td>
<td>46.8</td>
<td>24.7</td>
<td>42.6</td>
</tr>
<tr>
<td>37</td>
<td>44.1</td>
<td>7.0</td>
<td>26.9</td>
<td>32.5</td>
</tr>
<tr>
<td>42</td>
<td>38.4</td>
<td>22.9</td>
<td>30.0</td>
<td>23.3</td>
</tr>
<tr>
<td>74 (18 months post injury)</td>
<td>50.1</td>
<td>11.5</td>
<td>34.7</td>
<td>23.3</td>
</tr>
</tbody>
</table>

display a notable foot drop if she tried to walk at a brisk pace. She had returned to biking without limitation. Strength had steadily improved to 4/5 for hamstrings and 5/5 for eversion and hamstring recruitment was continuing to improve, however dorsiflexion strength did not display a consistent progression in strength staying at 2+/5. Over the next several weeks, the patient noted increased symptoms of diffuse numbness into her lower leg, below the level of the knee if she was not diligent with her home exercises. At week 20, due to the subject's schedule, she missed a few days of exercises and noted more numbness in her lower leg. This went away after she returned to diligently performing her exercises.

She attempted to begin a run/walk program in week 23, but this was difficult as she felt that she did not have as much control over her right foot. She continued to be seen in physical therapy every one to two weeks until week 33, at which point she was allowed to continue her care independently with a home exercise program.

**OUTCOMES**

Eighteen months after the patient's initial injury and 7 months after her discharge from physical therapy, she returned to the clinic for reassessment. She reported occasional numbness in the right lower leg which resolved with periods of walking. She reported she had returned to running up to 2 miles, 3 times per week and completed a 5 kilometer recreational run. She denied experiencing pain while running but she still described a sense of weakness in her involved extremity. She did not ski the winter following her injury due to fear of reinjury.

Objectively, on the HOS, the patient had improved from 65% to 98% for ADLs and 0% to 95% for sport activities when compared to her initial visit in physical therapy. Manual muscle testing was equal between legs, rated at 5/5 for all previously tested muscles, except great toe extension which was graded at a 4/5 bilaterally. Slump-sit testing revealed slightly more tension on the left leg versus the right but motion was equal. Hamstring flexibility via a passive straight leg raise was 86 degrees of hip flexion on the right and 92 degrees on the left.

Analysis of peak torque via Biodex™ testing (Table 3) revealed a deficit in knee flexion strength of 11.5% at 60 deg/sec and 23.3% at 180 deg/sec when compared to the uninvolved leg. This demonstrates a 50.6 percentage point improvement at 60 deg/sec and 26.6 percentage point improvement at 180 deg/sec when comparing the initial testing session to last testing session. The deficit that remains at the faster testing speed illustrates the patient's incomplete recovery, particularly for higher level activities that require faster speeds of muscular contraction, such as those required in athletics. Table 3 shows the progression of strength via Biodex™ testing over the 6 tests that were performed during the course of PT.

**DISCUSSION**

In this case, a patient was able to return to near full function following a sciatic nerve injury that occurred following a grade 3 hamstring tear. This is the first
In this case, the patient’s symptoms did not start to appear until after she reinjured her leg in a seemingly minor slip on a floor 28 days after the initial injury. This is similar to 2 previous case reports in the literature, where neural symptoms did not appear in subjects until after a subsequent injury. This delayed onset of neural symptoms may indicate that the injury was due more to excessive traction on the nerve sustained during the re-injury/slip versus true entrapment by scar tissue from the initial muscle injury. It is also possible that the injured hamstring muscle did not reactively contract during the re-injury/slip, contributing additional traction/stress to the nerve, thereby exacerbating symptoms.

In retrospect, neural symptoms that presented in this case may not have been recognized immediately by the treating therapist. Nerve glides were not instituted until the patient returned to PT in week 12 after consultation with MDs (8 weeks after onset of neural symptoms). Increased awareness of the possibility of sciatic nerve concurrent injury associated with or following a hamstring injury may have led to quicker recognition of signs and symptoms and as a result earlier intervention addressing the nerve issues. In turn, earlier intervention may have led to quicker resolution of symptoms. However, with a traction type injury sustained during the slip/re-injury as hypothesized in the previous paragraph, earlier institution of nerve gliding may have been detrimental and more gentle nerve mobility interventions may have been more appropriate.

Foot drop due to nerve entrapment following hamstring tears is rarely reported in the literature. To date, only surgery has been reported as an intervention to address the nerve entrapment. The outcomes described by the authors of this case report demonstrate how conservative rehabilitation incorporating strengthening, stretching, proprioceptive training, neural glides and electrical stimulation had the potential to allow the described patient to achieve satisfactory outcomes without the added cost and risks of surgery.

In summary, this case report documents the successful recovery of a patient from a hamstring tear with sciatic nerve involvement through the use of conservative measures. The subject sustained a hamstring tear...
torn tendon that led to nerve involvement after reaggravation of the initial injury. EMG findings revealed severe denervation of the tibialis anterior and biceps femoris. Objectively, patient had weakness in these muscles and demonstrated a foot drop during ambulation. Through a rehabilitation program emphasizing sciatic nerve glides and open and closed chain strengthening, the subject was able to return to almost all desired activities. She scored 95% on the sports subscale of the HOS and 98% on the ADL subscale at 18 months post injury. This is the first published case report in the literature describing recovery from sciatic nerve involvement after a hamstring tear that did not involve surgical intervention.

REFERENCES
Appendix 1. *The Hip Outcome Scale (Used with permission of Gunderson Lutheran Sportsmedicine)*

### Hip Outcome Scale (HOS)
#### Activities of Daily Living Subscale

Please answer *every question with one response* that most clearly describes your condition within the past week. If the activity in question is limited by something other than your hip, mark *not applicable (N/A)*.

<table>
<thead>
<tr>
<th>Activity</th>
<th>No difficulty at all</th>
<th>Slight difficulty</th>
<th>Moderate difficulty</th>
<th>Extreme difficulty</th>
<th>Unable to do</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing for 15 minutes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Getting into and out of an average car</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Putting on socks and shoes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking up steep hills</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking down steep hills</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Going up 1 flight of stairs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Going down 1 flight of stairs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stepping up and down curbs</td>
<td></td>
<td></td>
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<tr>
<td>Deep Squatting</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Getting into and out of a bath tub</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Sitting for 15 minutes</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Walking initially</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Walking approximately 10 minutes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Walking 15 minutes or greater</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
### Appendix 1. Continued.

Because of your hip how much difficulty do you have with:

<table>
<thead>
<tr>
<th></th>
<th>No difficulty at all</th>
<th>Slight difficulty</th>
<th>Moderate difficulty</th>
<th>Extreme difficulty</th>
<th>Unable to do</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twisting/ pivoting on involved leg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rolling over in bed</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Light to moderate work (standing, walking)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Heavy work (push/pulling, climbing, carrying)</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Recreational activities</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

How would you rate your current level of function during your usual activities of daily living from 0 to 100 with 100 being your level of function prior to your hip problem and 0 being the inability to perform any of your usual daily activities?

___ ___ ___.0%
### HOS - Sports Subscale

**Because of your hip how much difficulty do you have with:**

<table>
<thead>
<tr>
<th>Activity</th>
<th>No difficulty at all</th>
<th>Slight difficulty</th>
<th>Moderate difficulty</th>
<th>Extreme difficulty</th>
<th>Unable to do</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Running one mile</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jumping</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Swinging objects like a golf club</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starting and stopping quickly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cutting / lateral movements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low impact activities like fast walking</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to perform activity with your normal technique</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to participate in your desired sport as long as your would like</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**How would you rate your current level of function during your usual sports related activities from 0 to 100 with 100 being your level of function prior to your hip problem and 0 being the inability to perform any of your usual daily activities?**

___ ___ ___ 0%

**Overall, how would you rate your current level of function?**

- Normal
- Nearly normal
- Abnormal
- Severely Abnormal
ABSTRACT

Rehabilitation following lateral side knee ligament repair or reconstruction has traditionally utilized a conservative approach. An article outlining a new concept in rehabilitation following ACL reconstruction called the Knee Symmetry Model was recently published. The Knee Symmetry Model can also be applied to rehabilitation of other knee pathologies including a knee dislocation with a lateral side injury.

This Clinical Commentary describes the rehabilitation procedures used with patients who underwent surgery to repair lateral side ligaments, based upon the Knee Symmetry Model. These procedures were used previously to rehabilitate a group of patients with lateral side ligament repair as reported by Shelbourne et al. Outcome data and subjective knee scores for these patients were recorded via the International Knee Documentation Committee (IKDC) guidelines and modified Noyes survey scores and are summarized in this paper, as previously published. Rehabilitation following lateral side knee ligament repair using guidelines based upon the Knee Symmetry Model appears to provide patients with excellent long-term stability, normal ROM and strength, and a high level of function.

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INTRODUCTION

Lateral side ligament injuries (including any or all of the lateral side structures) which occur as a result of a knee dislocation are quite rare when compared to other knee ligament injuries. In addition, there is controversy surrounding the acute treatment of these injuries. However, most authors agree that knee dislocations with acute lateral side knee ligament injuries should be surgically treated within three weeks of injury. Some surgeons advocate reconstruction, others meticulously repair the involved tissues, while others prefer to surgically repair the injured ligaments as a unit in an “en masse” technique. The presence of an anterior cruciate ligament (ACL) or posterior cruciate ligament (PCL) injury further complicates the surgical decision making for lateral side ligament injuries.

Regardless of differences in surgical intervention, the rehabilitation provided following varied procedures should be examined and described. Due to the large amount of stress placed on the lateral side knee ligaments during normal activities of daily living (ADL) and sport, many surgeon/physical therapist teams take a conservative approach to rehabilitation. This is especially evident during the early stages of rehabilitation as range of motion limitations and weight bearing restrictions are typically implemented.

Rehabilitation of the knee following surgical repair of the lateral side knee ligaments is dependent on several important concepts. First, communication between the physician and the physical therapist needs to include the pre-operative diagnosis, as well as the surgical findings and surgical procedures utilized. Second, optimal outcomes occur when surgery is performed within three weeks of the injury. Third, since knee dislocations with lateral side ligament injuries rarely occur in isolation, other ligament injuries must be considered in the rehabilitation process.

Recently, an article describing a rehabilitation approach following ACL reconstruction was published. In that article the authors describe a “Knee Symmetry Model” (KSM) for post-operative rehabilitation of the ACL. The primary principle governing rehabilitation in the KSM is to restore symmetry between the involved and uninvolved knee. Several important measurable items for knee symmetry are considered in the implementation of this model. These include subjective outcome measures and objective measures of range of motion (ROM), stability, and strength. Although the KSM was initially described for rehabilitation following ACL reconstruction, its principles can also be applied to a variety of other surgical and non-surgical knee pathologies. The principles of the KSM were applied to a group of patients who underwent a lateral side repair associated with a knee dislocation. The outcomes were previously reported by Shelbourne and Haro and demonstrated the KSM safely and effectively restored ROM, strength, and function. The details surrounding the implementation of the KSM utilized in the rehabilitation following lateral side knee ligament repair are described in this clinical commentary.

DIAGNOSIS OF LATERAL SIDE KNEE LIGAMENT INJURIES

Injuries to the lateral side are rare events; however when they do occur it is generally part of a multi-ligament knee injury or knee dislocation. A knee dislocation is defined as a grossly unstable knee with at least 2 of the 4 ligamentous structures of the knee involved. Injuries to the lateral side often occur in combination with injury to the ACL and/or PCL. The mechanism of injury is generally attributed to high velocity motor vehicle accidents or low velocity injuries that occur during sports like football, soccer, and basketball.

The pre-operative diagnosis is made via history, physical examination, and MRI evaluation. Since ACL and/or PCL injuries may occur in conjunction with lateral side injuries, the physical examination incorporates assessment of all four of the major knee ligaments.

In 2007, Shelbourne and Haro reported a case series for 21 patients who sustained a knee dislocation and a lateral side injury. The pre-operative diagnosis for these cases is listed in Table 1. (Reprinted with permission from SAGE Publications Inc.) All but two patients had an ACL, PCL and lateral side knee injury; one patient had an ACL and lateral side injury and the other had a PCL and lateral side injury. All associated ACL injuries were reconstructed, while all associated...
PCL injuries were left in situ because they have been shown to heal with satisfactory results. The principles of the KSM were applied to this group of patients, and the rehabilitation program utilized along with the results are reported in this clinical commentary.

**PRE-OPERATIVE REHABILITATION**

Pre-operative rehabilitation goals are to increase ROM and decrease swelling/effusion. Patients are prescribed an anti-embolism stocking, a cold-compression device, and a continuous passive motion (CPM) machine to assist in accomplishing these goals. Patients undergoing ACL reconstruction are expected to have symmetrical ROM and no swelling prior to surgery, but this may not be attainable because of the necessity of early surgical intervention with lateral side knee ligament injuries. However, patients work on both passive and active ROM exercises in attempt to achieve at least 0 degrees of knee extension to 130 degrees of knee flexion prior to surgery. Commonly, 1-2 pre-operative physical therapy visits are necessary in order to achieve the pre-operative goals.

**SURGICAL PROCEDURES**

The surgical procedures used for both the lateral side ligament repair and the ACL reconstruction have been described in detail elsewhere. In the event a patient is greater than 3 weeks post injury and has been immobilized, a staged surgical procedure is performed. The lateral side procedure is performed first followed by an ACL reconstruction at a later date, if necessary, in order to prevent the potential complication of a stiff knee.

If an ACL reconstruction is performed in conjunction with the lateral side ligament repair a two-incision mini-arthroscopy technique is utilized. Both ipsilateral and contralateral autogenous bone-patellar tendon-bone grafts may be used for the reconstruction, however in the practice of the authors the majority of patients receive a contralateral graft. Posterior cruciate ligament tears are left in-situ secondary to the inherent healing abilities of this ligament. When peroneal nerve injuries are present they are not explored.

---

**Table 1. Patient demographics. Status of the knee at the time of surgery as evaluated with MRI scan.**

(Reprinted with permission from Shelbourne et al. 2007)

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age</th>
<th>Mechanism</th>
<th>Time (wks) from Injury to Surgery</th>
<th>ACL</th>
<th>PCL</th>
<th>Lateral Capsule</th>
<th>LCL</th>
<th>IT Band</th>
<th>Lateral Gastroc</th>
<th>Popliteus</th>
<th>Biceps Femoris</th>
<th>Neurovascular</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22.7</td>
<td>football</td>
<td>1.6</td>
<td>torn</td>
<td>torn</td>
<td>torn</td>
<td>torn</td>
<td>intact</td>
<td>intact</td>
<td>NR</td>
<td>torn</td>
<td>intact</td>
</tr>
<tr>
<td>2</td>
<td>31.5</td>
<td>football</td>
<td>4.3</td>
<td>torn</td>
<td>torn</td>
<td>torn</td>
<td>torn</td>
<td>intact</td>
<td>intact</td>
<td>torn</td>
<td>torn</td>
<td>intact</td>
</tr>
<tr>
<td>3</td>
<td>17.3</td>
<td>football</td>
<td>1.6</td>
<td>torn</td>
<td>torn</td>
<td>torn</td>
<td>torn</td>
<td>intact</td>
<td>intact</td>
<td>torn</td>
<td>torn</td>
<td>intact</td>
</tr>
<tr>
<td>4</td>
<td>29.7</td>
<td>softball</td>
<td>5.9</td>
<td>torn</td>
<td>torn</td>
<td>torn</td>
<td>torn</td>
<td>intact</td>
<td>intact</td>
<td>torn</td>
<td>torn</td>
<td>intact</td>
</tr>
<tr>
<td>5</td>
<td>26.0</td>
<td>football</td>
<td>4.9</td>
<td>torn</td>
<td>torn</td>
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*aACL, anterior cruciate ligament; PCL, posterior cruciate ligament; MVA, motor vehicle accident; NR, not reported*
A mini-arthrotomy to surgically reconstruct the ACL is utilized. Given that the lateral capsule is injured with lateral side disruptions, fluid extravasation is a problem when performing arthroscopic ACL surgery. The mini-arthrotomy eliminates the problem of fluid extravasation (which would occur with an arthroscopic approach) and allows for direct visualization of the ACL graft tunnels. In order to prevent overstressing the lateral repair, the ACL reconstruction is performed prior to the lateral repair. The ACL graft is tensioned at 30 degrees of flexion after the lateral repair is complete.

The repair technique for the lateral side ligament injury is described as an “en masse” surgical repair. This procedure is performed via a longitudinal incision from the tibial tubercle to the fibular head with the lateral side surgically exposed in a distal to proximal fashion. The distal to proximal approach is performed due to greater distal disruption thus preventing a large or unnecessary exposure. At the time of surgery (approximately 7-10 days post-injury) the lateral structures have already formed a healing mass (lateral capsule, lateral collateral ligament, popliteus tendon, biceps femoris tendon) covered by a pseudomembrane. To properly visualize the healing mass, the pseudomembrane must be entered. Once the injured area has been thoroughly investigated, the healing tissue is re-attached “en masse” to the anatomical attachment of the lateral capsule with a combination of staples and sutures. The “en masse” approach is utilized due to the strong connection between the structures in the healing mass. Thus the “en masse” technique allows the surgeon to take advantage of the body’s healing response in this area rather than individually repairing each component of the lateral side ligaments. Although the “en masse” approach does not anatomically restore the biceps tendon and the lateral collateral ligament to their original position on the fibula, they are very close to this position once the procedure is complete. When the biceps femoris tendon is torn off the fibula, but is not part of the healing mass, it is reattached to the fibula with a suture anchor. The iliotibial band is not normally torn.

After completion of the lateral repair and ACL reconstruction, the knee is moved from 0 degrees extension to at least 90 degrees of flexion. Prior to leaving the operating room, a subcutaneous drain is placed in the knee, an anti-embolism stocking is placed on the lower leg, and a cold compression device is placed on the leg to assist in swelling reduction.

**POST-OPERATIVE REHABILITATION**

**General Guidelines**

When using the KSM for ACL post-operative rehabilitation the ultimate goal of treatment is to regain symmetry of the knees. The same goals are true for a patient with a lateral side knee ligament injury repair. To attain these goals, ROM and strength become the primary objective measures, and symmetry in these measures is the goal. The patient’s ability to return to their previous level of activity without knee pain or swelling is also emphasized. It is important to note that there are no time lines for achievement of any of the post-operative goals described in this clinical commentary. Patients are progressed in accordance to their own unique healing abilities and progression. Initial post-operative goals are to prevent effusion and swelling. Restoration of symmetrical range of motion and strength are achieved according to patient tolerance.

Return to sports can occur once the patient has achieved good stability, symmetrical ROM and strength, and he/she is comfortable with the rigors of their activity. The criteria used for return to activity include ROM measures, KT2000 stability testing, isokinetic strength testing, and a single leg hop test. The authors use the International Knee Documentation Committee (IKDC) guidelines to define symmetrical ROM: knee extension within 2 degrees and knee flexion within 5 degrees from the non-involved knee. Symmetrical strength (for both isokinetic testing and single leg hop) is defined as strength between 90-100% of the performance of the non-involved knee. Normal stability is a side to side difference of less than or equal to 3 millimeters on the KT2000. To emphasize, when utilizing the KSM for rehabilitation time is not a factor in the progression of the program.

**Immediate Post-Operative Rehabilitation**

In the immediate post-operative period, patients remain in the hospital overnight and receive Ketorolac intravenously to assist with pain and swelling.
are utilized for knee flexion (Figure 1) while knee extension is achieved with a heel prop (Figure 2). Patients are taught to measure their own flexion ROM with the use of a yard stick. This helps the patient monitor his/her progress while at home the first week (Figure 3) (Table 2).

Intermediate Post-Operative Rehabilitation
After the first week of bed rest, patients are allowed to resume normal activities of daily living. Full control. An anti-embolism stocking remains on the leg along with a cold/compression device (Cryocuff™, DJ Orthopaedics, Vista, CA) for additional swelling and pain control. Patients remain supine with the reconstructed/repaired limb elevated in a CPM above the level of their heart during the first week after surgery in order to help prevent a hemarthrosis. Patients are allowed to ambulate for bathroom privileges only. During ambulation, patients are allowed to bear full weight with the use of a leg immobilizer and with or without crutches as necessary for additional support and comfort. The authors have found that limiting the activity level during the first week post-operatively ensures that the patient does not develop excessive swelling and effusion. By minimizing swelling, the patient experiences less pain and regains full ROM more easily.

A continuous passive motion (CPM) machine is initiated immediately following surgery. The CPM unit allows the patient to work on knee flexion ROM while maintaining the limb in an elevated position, important for swelling control. During the first week after surgery, the patient remains supine with the reconstructed/repaired leg in the CPM set at 0-30° for 24 hours a day with the exception of exercise sessions or bathroom privileges. Patients are instructed to perform the following exercises four times per day. A passive stretch is performed in the CPM by adjusting it to flex the knee up to 125° and is held for 1 minute. The patient then removes his/her leg from the CPM and performs a heel slide. Heel slides

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achieve symmetric knee flexion and extension. Patients are progressed as tolerated with no imposed time frames for achievement of their post-operative goals. Range of motion and strength activities are continued until bilateral knee symmetry is achieved. The emphasis of rehabilitation turns to strength and functional movement once symmetrical ROM has been achieved. As mentioned earlier the authors use both ipsilateral and contralateral bone-patellar tendon-bone graft sources for ACL reconstruction. The graft source determines the timing and emphasis of strength training. In most cases, the surgical technique chosen by the authors uses the contralateral patellar tendon graft which allows for early and immediate strengthening of the donor graft knee.19 Patients are instructed to perform step down, single leg extension and single-leg press exercises to strengthen the knee from which the donor graft was obtained while working on ROM and swelling.

weight bearing with the immobilizer is encouraged and crutches are only used for support or balance until the patient is comfortable walking without them. When the patient can demonstrate good leg control via good quadriceps activation and straight leg raises, the leg immobilizer is discontinued. In some cases, damage to the common peroneal nerve can lead to foot drop. The authors utilize a spring loaded ankle foot orthosis to assist with ankle dorsiflexion. In the case series reported by Shelbourne et al, 3 patients had complete peroneal nerve injury and wore an AFO for daily activities and sports.10

During the intermediate phase of rehabilitation the goals are to achieve bilaterally symmetrical ROM and strength. Both hyperextension and flexion range of motion continue to be emphasized, while symmetrical knee strength is also pursued. In addition to heel props and heel slides patients utilize wall slides (Figure 4) and towel extensions (Figure 5) to achieve symmetric knee flexion and extension. Patients are progressed as tolerated with no imposed time frames for achievement of their post-operative goals. Range of motion and strength activities are continued until bilateral knee symmetry is achieved. The emphasis of rehabilitation turns to strength and functional movement once symmetrical ROM has been achieved. As mentioned earlier the authors use both ipsilateral and contralateral bone-patellar tendon-bone graft sources for ACL reconstruction. The graft source determines the timing and emphasis of strength training. In most cases, the surgical technique chosen by the authors uses the contralateral patellar tendon graft which allows for early and immediate strengthening of the donor graft knee.19 Patients are instructed to perform step down, single leg extension and single-leg press exercises to strengthen the knee from which the donor graft was obtained while working on ROM and swelling.
control in the ACL reconstructed knee. The authors’ rehabilitation program focuses on single-leg strength training activities rather than double-leg activities because double-leg exercises such as squats and double-leg press tend to reinforce the stronger limb. In the event an ipsilateral patellar tendon graft is utilized, strength training for the involved knee occurs after full ROM is achieved. The same single-leg strength training is emphasized and progressed as long as no loss of ROM occurs.

The progression of the described rehabilitation has no imposed time frames, testing measures are implemented at specific times in order to monitor progress, guide rehabilitation, and advise regarding readiness for return to activities and sports. ROM measures are initiated immediately and stability testing using the KT-2000 usually begins approximately 1 month after surgery when swelling has decreased, extension is symmetrical, and flexion is at least 120°. Isokinetic strength testing (without the use of an extension block) usually occurs first around 2 months because by this time patients have appropriate ROM and have initiated a strengthening program that allows them to perform the testing. Ultimately the patient is expected to have symmetrical quadriceps and hamstring strength as well as normal unilateral quadriceps and hamstring strength ratios.\textsuperscript{20,21} Bilateral quadriceps and hamstring strength is evaluated at 180 and 60 degrees per second with an isokinetic device. When the patient achieves at least 80% strength with isokinetic testing, a single leg hop test is also used to determine readiness in returning to agilities and competition.\textsuperscript{22} Sport related activities such as light jogging and shooting a basketball are initiated once the patient has achieved bilaterally symmetrical ROM and 80% strength compared to the contralateral limb, or 80% of pre-operative normal values when a contralateral graft is used. While these activities are normally initiated at 2-3 months post-surgery, progression is based on criteria and not by time. The KT-2000 arthrometer test is performed during follow up visits at 2, 4, 6, 9 months and 1 year to monitor stability.\textsuperscript{23}

**Return to Activity Phase**

Strength testing is performed at 2 months after surgery. This includes open kinetic chain (OKC) isokinetic

**Figure 4.** In supine with buttocks close to the wall and heels on the wall, the patient allows the heel to slide down the wall flexing the knee.

**Figure 5.** The patient holds on to the ends of a towel that is wrapped around the ball of the foot. While using one hand to hold part of the leg above the patella down on the table, the other hand pulls the ends of the towel so that the knee is hyperextended and the heel lifts off the table.
testing at 180 and 60 degree per second speeds, an isometric leg press test and when appropriate, a single-leg hop test. When strength parameters are within 80% of the contralateral side, or 80% of pre-operative normal values when a contralateral graft is used, a functional progression for return to sport is implemented. The functional progression used by the authors begins with individual agility drills followed by sport specific drills. Patients can return to their sport once they have completed the functional progression necessary for their sport. Generally patients treated by the authors return to sports from a lateral side knee ligament repair in 4-6 months post surgery. To follow patient progress and to gain a greater understanding of long term results, patients are asked to complete an outcome questionnaire (International Knee Documentation Committee – IKDC) at 6 months, and 1, 2, 5, and 10 years post surgery.24

OUTCOMES

The results from a recent case series of 21 patients with lateral side ligament injuries rehabilitated using the KSM has been reported in the literature. Subjective evaluations occurred for 21 patients at 5.6 years postoperatively and mean objective measures for 17 patients at 4.6 years postoperatively. The objective measures for the 17 patients are contained in Tables 1

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*International Knee Documentation Committee; Inv, involved; Noninv, noninvolved; NA, not available

*Complete peroneal nerve injured patients
and 3. Additionally, Tables 4 and 5 contain objective information for this group of patients. Table 3 outlines the post-operative outcome measures from our previous publication.10 (Reprinted with permission from SAGE Publications Inc) Subjective scores obtained at a mean of 5.6 years postoperatively for the IKDC questionnaire and the modified Noyes survey were 91.3 and 93.0 respectively (Table 4). Sixteen out of 17 patients achieved normal knee ROM and 1 patient achieved nearly normal ROM (Table 5). Fifteen patients achieved greater than 90% strength at 180 degree isokinetic strength testing, and 16 patients achieved greater than 90% strength at 60 degree isokinetic strength testing (Table 6). Sixteen patients had greater than 90% on the single leg hop test. The mean KT2000 manual maximum difference was 2.2 ± 1.3 mm. The mean activity level was an 8.9 out of 10 points.26 Of the 16 patients injured in sports, 13 were able to return to the same level of athletic competition after surgery at a mean of 5.9 months after surgery.

**DISCUSSION**

This is the first article that describes rehabilitation procedures using the KSM following lateral side knee ligament repair. This article is designed to complement the surgical procedure described in the literature by Shelbourne et al in 2007.10 Many of the articles written on lateral side injuries provide minimal to no description of the rehabilitation associated with a particular surgical procedure.3,4,5,9,11,27,28 In particular it should be emphasized that hyperextension of the knee is considered in the KSM. The authors believe that restoration of hyperextension equal to the contralateral or uninjured side is an important goal of rehabilitation not only after ACL reconstruction, but also after lateral side ligament repair. All of the range of motion measures utilized in the KSM, including hyperextension, are compared to the contralateral side. The authors are unable to find other articles which specifically report restoration of symmetrical and equal knee hyperextension as part of the rehabilitation program or the outcome measures in patients following lateral side ligament surgery. Therefore, the application of the KSM for rehabilitation following a lateral side ligament injury with subsequent repair was thoroughly described.

The KSM has previously been applied to rehabilitation following ACL reconstruction.13 This rehabilitation program focuses on restoring the involved extremity to be symmetrical in ROM, strength and function to the opposite side. Patients are allowed to progress as quickly as possible and time constraints are no longer the limiting factor. Instead, patients progress based on their own healing potential and various objective criteria with knee symmetry as the ultimate goal.

Traditionally, rehabilitation following lateral side knee ligament repair is more conservative than ACL post-operative rehabilitation. Many protocols have significant restrictions on ROM, limit weight bearing, and require the use of a brace post-operatively.9,11,12 However, due to the type of surgery and the strength of the surgical fixation with the lateral side repair, the authors of this commentary believe the KSM for rehabilitation does not require any of these restrictions or limitations.

The results reported by Shelbourne and Haro7 demonstrate that the rehabilitation using the KSM can provide excellent outcomes for patients who

<table>
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<tr>
<th>Table 4. Mean Subjective and Objective Scores.7</th>
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<tr>
<td>Mean IKDC subjective score</td>
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<tr>
<td>Mean modified Noyes subjective score – ACL-reconstructed knee (100 points possible)</td>
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<tr>
<td>Activity Rating</td>
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<td>Mean KT 2000 at 30 lbs</td>
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<td>Mean KT 2000 Manual Max</td>
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7International Knee Documentation Committee

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<tr>
<th>Table 5. The number of patients in each ROM category as defined by the International Knee Documentation Committee.7</th>
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<td>----------------</td>
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<td>17</td>
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7Based on criteria set forth by the International Knee Documentation Committee; based on side to side differences

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<tr>
<th>Table 6. Frequency Distribution for Quadriceps Muscle Strength at 180° and 60°/second.</th>
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<tr>
<td>Percentile</td>
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<td>80-100%</td>
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<tr>
<td>60-79%</td>
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<td>00-59%</td>
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*Percentile = Side to Side Difference
*Inv = ACL-reconstructed knee
*Non = Grail-donor knee or opposite knee
were described in the current paper. The outcomes previously reported revealed excellent results both subjectively and objectively. Based upon the existing data, it appears the KSM can be successfully applied during rehabilitation following lateral side knee ligament repair. Further studies examining the application of the KSM with larger samples, other knee injuries, and additional surgical procedures are warranted.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Tinker Gray, MA, ELS and Kanitha Phalakorkule for their contributions to this clinical commentary.

REFERENCES


CONCLUSIONS

Results from another study reported on the outcomes of patients who underwent ACL reconstruction and lateral side knee ligament repair and utilized the rehabilitation principles of the KSM. The principles of the KSM as applied to these patients underwent lateral side repair. Previous reports have demonstrated that patients who achieve symmetrical knee ROM have better outcomes than patients who have less than normal ROM. Thus the emphasis of the KSM guided rehabilitation program is to restore normal knee ROM equal to the opposite knee. In the follow-up on the patients in the case series, 16/17 patients achieved normal ROM as defined by the IKDC criteria. In contrast; other authors report ROM problems following lateral side surgery and repair. In a study by Harner, et al only 17 out of 31 patients achieved normal knee extension and only 9 out of 31 patients achieved normal flexion. Fanelli and Edson also reported ROM problems with a mean loss of 10 degrees of flexion following PCL-posterolateral reconstructions. Chhabra et al reported restoration of knee extension within 1 degree and knee flexion within 12 degrees of the contralateral side. However, as described earlier, the descriptions of rehabilitation and range of motion outcomes in other articles do not specifically outline measurement of knee hyperextension. The primary goal of rehabilitation using the KSM is to restore symmetric motion, including symmetric hyperextension, as soon as tolerable by the patient. The early emphasis on ROM assists in prevention of post-operative ROM problems and subsequent complications.

Subjective data was collected in the case series by Shelbourne et al using the IKDC survey and the modified Noyes survey. The mean scores were 91.3 and 93.0 respectively. The mean age of the patients at the time of subjective follow up was 27 years, and the outcome scores were comparable to normative data collected and published by Anderson et al. Anderson et al reported mean subjective scores of 94.6 for men and 92.5 for women between the ages of 25 and 34 years old who had a normal knee with no previous injury or surgery. Therefore patients utilizing the KSM following lateral side repair not only achieve excellent objective outcomes, but also excellent subjective outcomes.


ABSTRACT

Chronic tendinopathy is a common musculoskeletal disorder that frequently affects athletes who train and compete at all levels. This Clinical Commentary presents a review of the etiology, incidence, and contributory factors related specifically to patellar tendinopathy. Examination and differential diagnosis considerations are provided, and an evidence-based, staged rehabilitation program is described.

Key Words. Jumper's Knee, patellar tendonitis
INTRODUCTION
Chronic tendinopathy is a common musculoskeletal disorder affecting both recreational and elite athletes potentially leading to disability lasting several months. Overuse tendon injuries account for 7% of the injuries seen in United States physician offices and 40% of knee injuries in volleyball players. Chronic patellar tendon conditions, also known as patellar tendinosis or “jumper's knee”, are numerous in elite athletes who run and jump as in volleyball (44%) and basketball (32%). Similar activity occurs in soccer and dancers, who also participate in repetitive kicking, jumping, and landing. A higher prevalence is noted in sports with high impact ballistic loading of the knee extensors. This disorder is a nemesis in weight lifters due to recurrent heavy load squatting. Patellar tendon overuse is also seen in military recruits, accounting for 15% of all of their soft tissue injuries and up to 22% incidence in the overall athletic population.

Microtrauma can occur when the patellar tendon is subjected to extreme forces such as rapid acceleration-deceleration, jumping, and landing. The posterior proximal patellar tendon is subjected to greater tensile tendinous forces as compared to the anterior region, especially with jumping activities and deep squat exercises, with forces up to 17 times body weight being placed on the patellar tendon in Olympic weight lifters. Patellar tendinopathy occurs more frequently in those skeletally mature adolescents or adults, ranging from ages 16-40 years. There is disagreement as to whether the incidence is more common in males than females, although recent studies show equal occurrences in both genders. Acute tendinitis involves an active inflammatory process, often occurring following an injury, which if treated, properly heals in 3-6 wks. In contrast, chronic patellar tendinopathy, also referred to as patellar tendinosis, manifests itself after 6 wks-3 months as degenerative changes occur in the tendon. These changes include absence of inflammatory cells in the tendon, a tendency toward poor healing, and decreased quality and disorganization of collagen fibers, both of which may lead to decreased tensile strength. Additionally, neovascularization, the growth of new vasculature in areas of poor blood supply, is common in chronic tendinopathy and may contribute to pain perception.

While the relationship between pain perception and neovascularization is not clearly understood, it is believed that increased levels of the neurotransmitter glutamate may play a role. Overuse in athletes who continue to push past pain may contribute to the development of a chronic and problematic condition taking 3-6 months to heal. Many factors, both intrinsic and extrinsic, contribute to patellar tendinopathy. Intrinsic factors such as strength imbalance, postural alignment, foot structure, reduced ankle dorsiflexion, and lack of muscle strength or flexibility may play a role. However the primary cause appears to relate to the extrinsic factor of overuse. For example, an increased physical load, repetition, intensity, frequency, and or duration of greater than 10% per week in the training schedule all contribute to this overuse syndrome. Additionally fatigue, poor technique, and training errors may play a role in this disorder. Further etiologic considerations for injuries may include improper training surfaces, insufficient footwear or inappropriate equipment. Progressing physical loading, high intensity training, or repetitive loading too fast may contribute to the development of patellar tendinopathy. This microtrauma or “overuse” injury develops from repetitive mechanical loading of the tendon through excessive jumping and landing activity. Training duration within a session or a season is the most common reason for overuse. Drastic changes in frequency and or intensity of training may also lead to overuse training errors. A general rule of thumb for acceptable progression of training is a 10% increase in intensity, duration, and frequency per week.

EVALUATION
The purpose of the evaluation is to differently diagnose between conditions affecting the patella. A comprehensive evaluation includes detailed examination of both intrinsic and extrinsic factors. A detailed history of a patient's workout schedule and duration of symptoms is paramount to making a correct diagnosis. If symptoms have lasted longer than 6 weeks, tendinopathy should be suspected. Evaluation of chronic patellar tendinopathy should include the utilization of Blazina’s knee scale or Kennedy’s scale (Table 1) which both assist the rehabilitation professional to gauge the severity of the tendinopathy. Patients with...
controlled rest is critical in the recovery of patellar tendinopathy. During this phase of rehabilitation, the athlete should refrain from sports activity or abstain from the overuse abuse, and practice controlled exercise without load.\textsuperscript{11,27} During this phase, patient education regarding activity is paramount. It is critical to recovery to avoid jumping or deep squatting (\textit{Table 2}). Progressing to relatively pain free activities, such as stationary cycling, performing exercises on a Total Gym®, or working in an aquatic environment can help maintain physical stamina, and yet unload the tendon. Kennedy et al\textsuperscript{23,28} suggested subjects with pain in stage 1 tendinopathy (pain only after activity) or stage 2 (pain during and after activity) adapt their training schedule, whereas subjects in stage 3 (pain during and after workouts that affects performance) may need total rest from aggravating activities.\textsuperscript{23,28} The athlete in stage 3 may still exercise aerobically, but must avoid irritating activities.\textsuperscript{23,28} Visnes et al\textsuperscript{29} reported that volleyball players who continued to train and compete during an eccentric rehabilitation exercise program showed no benefit from rehabilitation exercises. Therefore, Visnes et al\textsuperscript{29} suggested that patients be removed from sports participation while undergoing an eccentric-only rehabilitation program, then resume competitive sports training after 8 weeks, with a gradual return to sporting activity over the next 4 weeks.\textsuperscript{29,30}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
PHASES & BLAZINA JUMPER’S KNEE SCALE & KENNEDY TENDINOPATHY STAGES \\
\hline
PHASE 1 & Pain after activity only & Pain after activity \\
\hline
PHASE 2 & Pain/discomfort during and after activity with the subject still able to perform at a satisfactory level (does not interfere with participation) & Pain at the beginning and after activity \\
\hline
PHASE 3 & Pain during and after activity with more prolonged, with subject having progressively increasing difficulty in performing at a satisfactory level (interferes with competition) & Pain at the beginning, during, and after activity, but the performance is not affected \\
\hline
PHASE 4 & Complete tendon disruption & Pain at the beginning, during and after activity, and the performance is affected \\
\hline
\end{tabular}
\caption{Scales to assist in evaluating patellar tendinopathy.}
\end{table}

patellar knee pain may grade pain as general achingness after activity (Blazina Stage 1) to pain during and after activity which interferes with competition (Blazina Stage 3). Total tendon disruption is present in Blazina Stage 4.\textsuperscript{22} Physical examination during all stages reveals tenderness to palpation and pain over the inferior pole of the patella\textsuperscript{24} and possibly in the body of the tendon.\textsuperscript{24} Thickness of the tendon may be noted also in all stages, but it is rare to see effusion. Pain in the patellar tendon may be reproduced with resisted knee extension.\textsuperscript{24} Additional functional tests of ascending or descending stairs, performing single leg declining squats, jumping or hopping will most likely reproduce patellar pain symptoms.\textsuperscript{25} Patients such as weight lifters may complain of a “giving way” or a perception that knee will “buckle” under load as well as stiffness or achingness after activity.\textsuperscript{22} Additionally, they may complain of stiffness or achingness after activity (Blazina stage 3 or Kennedy Stage 4).

The evaluation should include history, age and any recent growth spurts, location of pain, and special tests. The rehab professional should be able to differentiate between patellar tendinopathy and additional diagnoses of 1) patellofemoral dysfunction (more diffuse patellar pain),\textsuperscript{12} 2) Sinding-Larsen-Johansson Syndrome (skeletally immature adolescents with pain in the inferior pole of the patella),\textsuperscript{26} and 3) Osgood Schlatter’s disease (skeletally immature adolescents with pain at the attachment of patellar tendon at the tibial tubercle with possible tibial tubercle enlargement).\textsuperscript{10}

**REHABILITATION**

**Stage 1: Initial Rehabilitation Controlled Rest**

Controlled rest is critical in the recovery of patellar tendinopathy. During this phase of rehabilitation, the athlete should refrain from sports activity or abstain from the overuse abuse, and practice controlled exercise without load.\textsuperscript{11,27} During this phase, patient education regarding activity is paramount. It is critical to recovery to avoid jumping or deep squatting (\textit{Table 2}). Progressing to relatively pain free activities, such as stationary cycling, performing exercises on a Total Gym®, or working in an aquatic environment can help maintain physical stamina, and yet unload the tendon. Kennedy et al\textsuperscript{23,28} suggested subjects with pain in stage 1 tendinopathy (pain only after activity) or stage 2 (pain during and after activity) adapt their training schedule, whereas subjects in stage 3 (pain during and after workouts that affects performance) may need total rest from aggravating activities. The athlete in stage 3 may still exercise aerobically, but must avoid irritating activities.\textsuperscript{23,28} Visnes et al\textsuperscript{29} reported that volleyball players who continued to train and compete during an eccentric rehabilitation exercise program showed no benefit from rehabilitation exercises. Therefore, Visnes et al\textsuperscript{29} suggested that patients be removed from sports participation while undergoing an eccentric-only rehabilitation program, then resume competitive sports training after 8 weeks, with a gradual return to sporting activity over the next 4 weeks.\textsuperscript{29,30}
<table>
<thead>
<tr>
<th>Week</th>
<th>Rest</th>
<th>Eccentric Exercise</th>
<th>Transverse friction mobilization</th>
<th>Stretching (30 secs x 3-4x)</th>
</tr>
</thead>
</table>
| 1    | *No jumping or running; can ride bike, do pool work; *No sports specific training | *Around the world eccentric lowering leg raises( 4 way) increase weight by 1# each week)  
*Eccentric squats on Total Gym/Shuttle on decline board 15 reps x 3 sets 1-2 x a day/ | 5-10 minutes firmly 1-2x a day | Hip flexors, quadriceps, hamstrings, & heelcords before/ after activity |
| 2    | *No jumping or running; can ride bike, do pool work; *No sports specific training | *Around the world eccentric lowering leg raises( 4 way) increase weight by 1# each week)  
*Eccentric squats on Total Gym/Shuttle on decline board 15 reps x 3 sets 1-2 x a day/ | 5-10 minutes firmly 1-2x a day | Continue stretching as above |
| 3    | *Begin jumping squats in short range on Total gym/Shuttle; *No sports specific training | *Around the world eccentric lowering leg raises( 4 way) (increase weight by 1# each week)  
*Eccentric squats on Total Gym/Shuttle on decline board 15 reps x 3 sets 1-2 x a day/; *Progress to upright decline board squats | 5-10 minutes firmly 1-2x a day | Continue stretching as above |
| 4    | *cycle, exercise in water; *Begin eccentric step downs standing (no step) *No sports specific training | *Upright squats on decline board double leg to single leg; add 10# to backpack;  
* Around the world eccentric lowering leg raises( 4 way) (increase weight by 1# each week) | As needed | Continue stretching as above |
| 5    | Begin eccentric step downs on 4” step; *No sports specific training | *Upright squats on decline board double leg to single leg; add 20# to backpack;  
*Continue Around the world eccentric lowering leg raises( 4 way) (increase weight by 1# each week)  
*Begin jumping squats on Total Gym/Shuttle with both legs | As needed | Continue stretching as above |
| 6    | *Begin eccentric step downs on 6”; *No sports specific training | *Upright squats on decline board double leg to single leg; add 30# to backpack;  
*Continue Around the world eccentric lowering leg raises( 4 way) (increase weight by 1# each week)  
*Jumping squats on Total Gym/Shuttle with both legs | As needed | Continue stretching as above |
| 7    | *Begin eccentric step downs on 8” step | *Upright squats on decline board double leg to single leg; add 40# to backpack;  
*Continue leg lifts with weights;  
* Jumping squats on Total Gym/Shuttle with single leg | As needed | Continue stretching as above |
| 8-12 | *Progressive return to jumping/squatting/ jump boxes; *Begin sports specific training with gradual return to sporting events | *Jumping squats on Total *Gym/Shuttle with single leg; *Upright squats on decline board with 50#”  
*Jumping squats one leg on Total gym/Shuttle with maximal resistance | As needed | Continue stretching as above |
Interventions
Rehabilitation incorporates three stages ranging from limited partial weight bearing loaded exercise to a sports specific return to play protocol. Since overuse is a primary contributor to patellar tendinopathy, it is important to avoid rapid progression in frequency, intensity, and duration in rehabilitation and functional progression. Since most athletes with patellar tendinopathy are treated non-operatively, it is imperative to understand rehabilitation protocols and implement them wisely. Eccentric exercise has been promoted as an important conservative treatment choice for patellar tendinopathy as well as for Achilles tendinopathy. However, a variety of protocols have been implemented for rehabilitation intervention. For example, the Alfredson protocol of eccentric exercise intensity to pain level up to 5/10 directly contrasts the early work of Stanish and Curwin who suggest that exercise only be performed without pain. Because no standard rehabilitation protocol has been established as it relates to pain symptoms secondary to tendinopathy, the following protocol has been developed by this author, involving a pain-free intervention progressing from partial body weight to full body weight positions.

Initial treatment for patellar tendinopathy includes the following: absence from jumping, relative rest (absence of abuse), stretching of lower extremity musculature, deep transverse friction massage of the patellar tendon, eccentric quadriceps exercises, strengthening of hip and knee musculature, utilization of a patellar orthotic (if needed), and cryotherapy. Since patellar tendinosis is a chronic, non-acute condition, inflammation is absent. Thus, anti-inflammatory medications (NSAIDs) are seldom effective. Additionally, the use of cortisone injections may negatively affect tendon strength and may possibly result in tendon rupture.

Prior to initiating exercise, a warm-up and stretching period is recommended. Cycling on a stationary bicycle for 5-10 minutes with minimal resistance is suggested as an active warm-up. Next, stretching should be incorporated into the program before and after the exercise routine in order to address any flexibility imbalances (Table 2). Hip flexor, quadricep, hamstring, and gastrocnemius and soleus tightness may contribute to tendon overload during jumping and landing activities. Lower extremity stretching of 15, 30, 45, or 60 seconds or 2 minutes produces significant gains in flexibility in healthy young or middle age adults. Static stretching of 30 seconds at least three to four times per day is recommended by various authors.

Soft tissue mobilization (STM) is used to reduce pain and fibrotic limitations in tissue found in patellar tendinopathies. Deep transverse friction massage for 5-10 minutes twice daily is recommended to help promote normalized collagen alignment. Hunter found that firm pressure during cross friction massage is more effective than light to moderate pressure. Use of a rigid instrument, such as a stainless steel or hard plastic tool, may provide accelerated early tissue level healing in ligamentous and tendinous injuries (Figure 1). Furthermore, STM applied transversely to the line of collagen fibers while the tissue is placed under tension may assist damaged tissue to regain tensile strength and proper fiber orientation in the early stages of healing. Patients can be educated to perform STM daily until tissue is normalized and pain is absent with palpation.

Eccentric exercises play an important role in chronic patellar tendinopathy rehabilitation. Performing eccentric squats on a 25° decline board for 3 set of 15 repetitions twice daily is suggested. Loading a tendon in a controlled environment free from overuse with progressive stress improves

Figure 1. Soft tissue mobilization. 1a: Deep friction with use of device (longitudinally). 1b: Deep friction with use of device (cross-friction).
tendon function.$^{31}$ A controlled tendon loading exercise program can be initiated through utilization of a Total Gym® (*Figure 2*), Shuttle® (*Figure 3*), or a pool. Using a decline board, more specifically targets the patellar tendon (25-30% higher patellar tendon forces)$^{35}$ as compared to squats performed on flat surfaces which more likely targets the quadriceps muscle. This specificity of tendon training allows the patient to progress faster than on a squat on flat surface secondary to a better isolation of the knee extensor mechanism. The patient performs partial weight bearing eccentric squats in a pain-free range of motion by placing a 25° decline board on a Total Gym® (*Figure 2*) or Shuttle® (*Figure 3*). Progression occurs as the angle of the Total Gym® or the resistance on the Shuttle® is increased. Likewise, a similar approach can be used in the pool with a decline board on the pool floor in shoulder deep water. Progression occurs from moving to waist deep water, then shallower hip deep water.

A patient is ready to progress when they can easily complete the 3 sets of 15 repetitions of eccentric squats on a decline board pain-free. As one improves, decline squats can increase in difficulty from bilateral eccentric to unilateral eccentric, then to concentric-eccentric contractions.$^{37,49}$ During the concentric phase of the squatting motion, initially one should use the unaffected leg to extend the knee, then lower eccentrically bilaterally; progressing to
single limb eccentrics using the affected leg. Additionally, speed should be addressed throughout rehabilitation. Bilateral slow speed decline squats are encouraged during the first week of rehabilitation while faster speeds are encouraged during the second week. Although pain reported by the patient of up to level 5/10 on the Visual Analog Scale is common with some of the documented eccentric progressions of exercise, other authors have found exercising without induced pain to be beneficial to healing. This non-painful protocol may benefit the non-athlete as well. Sayana et al found only 56% of non-athletic subjects benefitted from full weight bearing eccentric painful squat exercises. Therefore, this pain-free protocol is recommended by the author of this commentary for all individuals with patellar tendinopathy.

Squatting depths are controversial among health professionals and coaching instructors. Squatting should be limited to no greater than 60-70° knee flexion due to the excessive forces on the patellofemoral joint, patellar tendon, and the meniscus, although some studies encourage full depth squats to 90 degrees. Other patellar tendinopathy protocols had subjects performing squats slowly to 60° and 70° knee flexion respectively. Dillon et al found significantly greater forces on the posterior fascicles of the patellar tendon between 60-90° of squatting. Squatting depths can be easily controlled on a Total gym®, Shuttle®, or in the upright, full-weightbearing position.

A proximal hip and thigh strengthening program including “around the world” leg raises (straight leg raises, sidelying hip abduction /hip adduction and prone hip extension) with concentration on eccentric lowering is important (Figure 4). Hip strengthening exercise with a 2 second concentric leg lift, followed by a 4 sec eccentric leg lowering is encouraged. Hip strengthening exercises (with no weight initially) combined with the decline eccentric squats should be an essential element of injury and rehabilitation programs. Education of the patient to perform exercises at home is also key to full recovery.

Although ice has been shown to reduce inflammation in acute conditions, varied results are found with the use of ice in chronic conditions. Ice massage for

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**Figure 4.** “Around the World” leg raises. 4a. Straight leg raise 4b. Hip Abduction side leg raise 4c. Hip adduction inside leg raise 4d. Hip extension prone leg raise.
5 minutes or ice pack to the patellar tendon can be applied for up to 10 minutes following the exercise program. Knobloch et al found intermittent cryotherapy of 3 sets of 10 minutes significantly decreased local Achilles tendon mid-portion capillary blood flow by 71%, thus promoting venous capillary outflow in the tendon. Many common modalities, such as iontophoresis, ultrasound, and electrical stimulation have not been found to be effective in treatment of chronic tendinopathy. Extracorporeal shock wave therapy (ESWT) for patellar tendinopathy shows promise as a safe treatment based upon a literature review of seven studies, although no specific treatment regime is recommended. A systematic review of low level laser treatment (LLLT) shows potential effectiveness for treating tendinopathy when recommended dosages are used.

Orthotics or taping may be beneficial for patellar tendinosis. The Chopat strap, or other varied patellar tendon straps can help stabilize the tendon with jumping activities, and may be used during rehabilitation. Although various authors suggest use of such orthotics, no randomized controlled trials have been conducted examining their efficacy in patellar tendinosis, and therefore evidence is lacking to the effectiveness of a patellar strap. Further research need to be conducted regarding the use of such devices.

**Stage 2: Progression**

After pain symptoms decrease, progress the patient to upright 25° decline eccentric squats (3 sets of 15 repetitions twice daily), utilizing the bilateral-unilateral-eccentric-concentric progression as outlined previously. The eccentric exercise program should be progressed from partial-weight bearing to full weight bearing (Figure 5), then to weighted resistance using a back pack or weighted vest (Figure 6). Speed can be increased during the concentric-eccentric phase, finally progressing to more ballistic type activity (jump squats) to prepare for return to functional activities. Once symptoms have subsided, patients with tendinopathy should be encouraged to continue eccentric strengthening exercise even after their return to sport.

As previously mentioned, resistance weight may be added to the single squat eccentric, either through a weighted belt, vest or bag, or by using a backpack with weights. Once the subject can perform decline squats easily and without pain, weights can be added in 5 kg increments, starting with 10% of body weight. Double leg jumping squats on the Shuttle or Total gym® may be initiated at weeks 4-5 at a progressive resistance level that does not produce patellar pain. The stretching program as well as the “around the world” leg raise routine using progressive ankle weights (1-2# per week) should be continued. Additionally, deep-friction massage and ice following exercise should be
Avoidance of sports activity during the first 8 weeks is crucial for continued healing. Those who have continued to train and compete in sports activities during treatment progression have demonstrated little change in prognosis.29

Stage 3: Sports Specific: Return to Play

In this phase, the athlete should continue the above routine, adding more weight in 5 kg increments with the weighted eccentric decline squats. Progression to a drop squat, involving rapidly eccentrically dropping into a stationary squat position, should include 3 sets of 20 reps with incremental weight as above.69 Three sets of 15 repetitions daily of eccentric step downs off of 4”, 6” and 8” height steps performed with minimal to no discomfort are appropriate as well (Figure 7).54 Jumping activities can then be added to this routine. Progression of double leg jumping squats (involving concentric and eccentric jumping in a squat position repetitively) on the Shuttle® or Total gym® to a single leg jump should be initiated before beginning standing jumps. Following pain-free movement off of the 6-8” step down, progress to drop jumps.34,69 Progression includes drop jumping off small step (4”), progressing to 6” and 8” steps when 3 sets of 20 repetitions daily are maintained. At 4 weeks, slow pain-free jogging on flat ground, as well as resisted cycling or water jogging can be added.30

Figure 6. To progress patient, add weighted backpack.

Figure 7. Step Downs. 7a. Step down off 4” step. 7b. Step down off 8” step.
Position at a dosage of 3 sets of 15 repetitions twice daily for 12 weeks. Progressive jumping activities are added midway through the program. Other considerations may include slow progression back to sporting events after 2-3 months, assuming the tendon site is pain-free in all activities.

A variety of rehabilitation techniques are necessary to assist an individual in returning to recreational activities following patellar tendinopathy. A combination of active rest, education, eccentric exercise, progressing the training regime by 10% weekly, and modifying activity have all been found to be effective in tendinopathy treatment. 19, 70

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4. Khan KM, Maffulli N, Coleman BD, Cook JL, Taunton JE. Patellar tendinopathy: some aspects of

SUMMARY
While various rehabilitation techniques exist to treat patellar tendinopathy, eccentric exercise has been found to be safe and effective29,30,36,53 and should be included as part of the comprehensive rehabilitation of this pathology. Additionally, deep transverse friction massage, strengthening of the hip musculature and stretching are all suggested initially and throughout the recovery of this type of injury. The protocol presented in this commentary uses partial body weight decline eccentric squats as the initial exercise prior to progressing to upright, fully loaded decline squats. The rehabilitation specialist should include eccentric squats in a “safe” 60-70 degree knee flexion range on a decline board progressing from the partially loaded position to the upright position at a dosage of 3 sets of 15 repetitions twice daily for 12 weeks. Progressive jumping activities are added midway through the program. Other considerations may include slow progression back to sporting events after 2-3 months, assuming the tendon site is pain-free in all activities.

A variety of rehabilitation techniques are necessary to assist an individual in returning to recreational activities following patellar tendinopathy. A combination of active rest, education, eccentric exercise, progressing the training regime by 10% weekly, and modifying activity have all been found to be effective in tendinopathy treatment. 19, 70

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ABSTRACT

Suboptimal breathing patterns and impairments of posture and trunk stability are often associated with musculoskeletal complaints such as low back pain. A therapeutic exercise that promotes optimal posture (diaphragm and lumbar spine position), and neuromuscular control of the deep abdominals, diaphragm, and pelvic floor (lumbar-pelvic stabilization) is desirable for utilization with patients who demonstrate suboptimal respiration and posture. This clinical suggestion presents a therapeutic exercise called the 90/90 bridge with ball and balloon. This exercise was designed to optimize breathing and enhance both posture and stability in order to improve function and/or decrease pain. Research and theory related to the technique are also discussed.
INTRODUCTION

Many muscles used for postural control/stabilization and for respiration are the same, for example: the diaphragm, transversus abdominis, and muscles comprising the pelvic floor. Maintaining optimal posture/stability and respiration is important and is even more challenging during exercise. Exercise increases respiratory demand (e.g. running) and limb movements (e.g. arms moving while standing still) increase postural demands for stabilization. Maintaining an optimal balance of these muscles for both respiratory and postural/stability roles is challenging. Many factors are potentially involved with suboptimal respiration and suboptimal (faulty) posture and may be associated with musculoskeletal complaints such as low back pain, and/or sacroiliac joint pain.

One of the most critical factors, often overlooked by physical therapists, is maintaining an optimal zone of apposition of the diaphragm. The zone of apposition (ZOA) is the area of the diaphragm encompassing the cylindrical portion (the part of the muscle shaped like a dome/umbrella) which corresponds to the portion directly apposed to the inner aspect of the lower rib cage. The ZOA is important because it is controlled by the abdominal muscles and directs diaphragmatic tension. When the ZOA is decreased or suboptimal, there are several potential negative consequences. (Table 1) Two examples include:

1. Inefficient respiration (less air in and out) because the transdiaphragmatic pressure is reduced. The smaller the ZOA, there will be less inspiratory action of the diaphragm on the rib cage.

2. Diminished activation of the transversus abdominis which is important for both respiration and lumbar stabilization.

In an athletic population, low back pain (LBP) is one of the most common reasons for missed playing time by professional athletes. Low back pain is defined as pain that occurs between the 12th rib and the gluteal fold. This region includes the osseous structures and soft tissue of the lumbar segments and the sacroiliac joints (SIJs). The incidence of LBP has been documented to be as high as 30% in the athletic population, and in many cases pain may persist for years. Low back pain is frequently correlated with faulty posture such as an excessive lumbar lordosis. Excessive lumbar lordosis may be associated with over lengthened and weak abdominal musculature. Poor neuromuscular control of core muscles (transversus abdominis, internal oblique, pelvic floor and diaphragm) has been described in individuals with SIJ pain and in individuals with lumbar segmental instability, potentially adversely affecting respiration.

Rehabilitation programs prescribed by physical therapists with the goal of decreasing lumbar-pelvic instability via specific stabilization exercises have been shown to decrease LBP. These stabilization exercises utilize verbal and tactile cuing in order to educate the patient to voluntarily contract the transversus abdominis and multifidi via the abdominal drawing in maneuver (ADIM) in a variety of positions.

Table 1. Possible factors associated with suboptimal respiration and posture.

<table>
<thead>
<tr>
<th>Suboptimal Respiration and Posture</th>
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<tr>
<td>Decreased/suboptimal Zone of Apposition of diaphragm</td>
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<tr>
<td>Decreased exercise tolerance</td>
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<td>Decreased intra-abdominal pressure</td>
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<td>Shortness of Breath/Dyspnea</td>
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<td>Decreased respiratory efficiency</td>
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<td>Decreased expansion of lower rib cage/chest</td>
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<td>Decreased appositional diaphragm force</td>
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<td>Decreased length of diaphragm (short)</td>
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<td>Decreased transdiaphragm pressure</td>
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<td>Increased use of accessory muscles of respiration</td>
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<td>Poor neuromuscular control of core muscles</td>
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<td>Increased lumbar lordosis</td>
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<td>Increased anterior pelvic tilt</td>
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<td>Increased hamstring length</td>
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<td>Increased abdominal length</td>
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<tr>
<td>Rib elevation/external rotation</td>
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<td>Sternum elevation</td>
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<td>Increased activity of paraspinals</td>
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<td>Increased lumbar-pelvic instability</td>
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<td>Low back pain</td>
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<td>Sacroiliac Joint pain</td>
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<td>Thoracic Outlet Syndrome</td>
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<td>Headaches</td>
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<td>Asthma</td>
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such as supine, sitting, sit to stand, standing and single leg standing. Stabilization exercises have also included co-contraction exercises of the abdominals and lumbar extensor muscles. In spite of decreasing LBP with stabilization exercises, the rate of recurrence of LBP suggests that there may be a missing component to traditional stabilization exercise programs. Traditional stabilization exercises that have included transversus abdominis, multifidi and/or paraspinal activation are not always sufficient to prevent future episodes of pain. Perhaps stabilization exercises that encourage an optimal ZOA of the diaphragm which in turn promotes optimal activation of the transversus abdominis may further help to address suboptimal respiration and posture which may be associated with LBP.

Richardson et al. describe coordination of the Transversus abdominis and the diaphragm in respiration during tasks in which stability is maintained by tonic activity of these muscles. During inspiration, the diaphragm contracts concentrically, whereas the transversus abdominis contracts eccentrically. The muscles function in reverse during exhalation with the diaphragm contracting eccentrically while the transversus abdominis contracts concentrically. Hodges et al. noted that during respiratory disease the coordinating function between the transversus abdominis and diaphragm was reduced. Thus, it is also possible that faulty posture such as over lengthened abdominals and excessive lordosis could reduce the coordination of the diaphragm and transversus abdominis during respiration and stabilization activities.

O’Sullivan et al. studied subjects with LBP attributed to the sacroiliac joints and compared them to control subjects without pain. O’Sullivan et al. compared respiratory rate and diaphragm and pelvic floor movement using real time ultrasound during a task that required load transfer through the lumbo-pelvic region (the active straight leg raise test). Subjects with pain had an increase in respiratory rate, descent of their pelvic floor and a decrease in diaphragm excursion as compared to the control subjects, who had normal respiratory rates, less pelvic floor descent, and optimal diaphragm excursion. While O’Sullivan et al. concluded that an intervention program focused on integrating control of deep abdominal muscles with normal pelvic floor and diaphragm function may be effective in managing patients with LBP, they did not describe strategies or exercises to achieve this goal.

The purpose of this clinical suggestion is to discuss the clinical value for patients/athletes in performing an exercise called a 90/90 Bridge with Ball and Balloon by discussing the exercise as it relates to suboptimal respiration and posture.

**ANATOMIC BACKGROUND**

While the role of the Transversus abdominis in lumbar stability is well documented, less well known is the role of the diaphragm in lumbar stability. While the primary function of the diaphragm is respiration, it also plays a role in spinal stability. Subsequently, Hodges et al. conducted an electromyographic (EMG) study with five subjects who were required to rapidly flex their left arm at the shoulder (while in standing position) in response to a visual stimulus. The authors reported that the diaphragm is involved in the control of postural stability during sudden voluntary movement of the limbs. Subsequently, Hodges et al. reported in an EMG study that the separate demands on the diaphragm to control pressures in the thorax for breathing and abdomen for stabilization of the lumbar spine can be combined; however when the demand for breathing increases, the role of the diaphragm in postural stability declines.

The diaphragm is comprised of two separate muscles, the right hemidiaphragm and left hemidiaphragm, which are innervated by the right and left phrenic nerves respectively. The hemidiaphragm’s proximal attachment site is the central tendon. The section anterior and lateral to the central tendon attaches distally to the zyphoid process of the sternum and ribs 7-12 and is referred to as the costal border of the diaphragm. The overall shape of the diaphragm is a dome, with the apex (the central tendon) around the level of T8. The right hemidiaphragm attaches distally to the anterior portions of the first through third lumbar vertebrae (L1-3) and the left hemidiaphragm attaches distally on the first and second lumbar vertebrae (L1-2). This section of the diaphragm is referred to as the crura. Of interest is the asymmetrical attachment of the diaphragm with the left hemidiaphragm attaching to L1-2 and the right portion attaching to L1-3.
During the inhalation phase of ventilation, the dome of the diaphragm moves caudally like a piston creating a negative pressure in the thorax that forces air into the lungs. This action is normally accompanied by a rotation of the ribs outward (external rotation) largely in part due to the ZOA. Apposition is a term that means multiple layers adjacent to each other. The normal force of pull on the sternal and costal portions of the diaphragm would produce an internal rotation of the ribs. The ZOA creates an external rotation of these ribs primarily because the pressure in the thoracic cavity prevents an inward motion. The crural portion of the diaphragm assists the caudal motion of the dome. It also pulls the anterior lumbar spine upward (cephalad and anterior). Additionally, the abdominal muscles and pelvic floor musculature are less active to allow visceral displacement due to the dome of the diaphragm dropping. With exhalation, this process is reversed. Abdominal muscle activity compresses the viscera in the abdominal cavity, the diaphragm is forced cephalad and the ribs internally rotate. As exhalation becomes forced as during exercise, abdominal activity (rectus abdominus, internal obliques, external obliques, and transversus abdominis) will be increased.

When the ZOA is optimized, the respiratory and postural roles of the diaphragm have maximal efficiency. In suboptimal positions (i.e. decreased ZOA), the diaphragm has a decreased ability to draw air into the thorax because of less caudal movement upon contraction and less effective tangential tension of the diaphragm on the ribs and therefore lower transdiaphragmatic pressure. This decreased ZOA is accompanied by decreased expansion of the rib cage, postural alterations, and a compensatory increase in abdominal expansion. As a result, adaptive breathing strategies can develop. One such adaptive breathing strategy would be to relax the abdominal musculature more than necessary on inspiration to allow for thoraco-abdominal expansion. This situation leads to decreased abdominal responsibility while breathing and can contribute to instability. This would reflect more upper chest breathing and less efficient diaphragm activity. If the body maintains this position and breathing strategy for an extended period of time, the diaphragm may adaptively shorten and the lungs may become hyperinflated. Hyperinflation may also contribute to over use of accessory muscles of respiration such as scalenes, sternocleidomastoid (SCM), pectorals, upper trapezius and paraspinals in an attempt to expand the upper rib cage. Again, without an optimal dome shape/position of the diaphragm or an optimal ZOA the body compensates to get air in with accessory muscles since the more linear/flat/short diaphragm is less efficient for breathing.

**CLINICAL SUGGESTION/SOLUTION**

A therapeutic exercise that promotes optimal posture (diaphragm and lumbar spine position) and finely tuned neuromuscular control of the deep abdominals, diaphragm, and pelvic floor (lumbar-pelvic stabilization) would be desirable for patients with suboptimal respiration and posture which may
be associated with musculoskeletal complaints i.e. LBP and/or SIJ pain. The 90/90 Bridge with Ball and Balloon technique developed by the Postural Restoration Institute™ was designed to help restore the ZOA and spine to a proper position in order to allow the diaphragm optimal ability to perform both its respiratory and postural roles. The balloon blowing exercise (BBE) technique is performed in supine with the feet on a wall, hips and knees at 90 degrees and a ball between the knees. (Figure 3) This passive 90° hip and knee flexion position places the body in relative lumbar spine flexion, posterior pelvic tilt and rib internal rotation/depression which serves to optimize the ZOA and discourage lumbar extension/anterior pelvic tilt, paraspinal activity, and rib elevation/external rotation. When performed with active hamstring contraction the paraspinals are further inhibited due to the caudal pull of the hamstrings on the pelvis (specifically the ischial tuberosities) which further encourages lumbar flexion. Having a ball between the knees encourages adductor muscle activation (via hip adduction and internal rotation position) and co-contraction of the pelvic floor muscles (levator ani and coccygeus).

The patient/athlete is asked to hold the balloon with one hand and inhale through his/her nose with the tongue on the roof of the mouth (normal rest position) and then exhale through his/her mouth into the balloon. The inhalation, to about 75% of maximum, is typically 3-4 seconds in duration, and the complete exhalation is usually 5-8 seconds long followed by a 2-3 second pause. This slowed breathing is thought to further relax the neuromuscular system/parasympathetic nervous system and generally decrease resting muscle tone. Ideally the patient/athlete will be able to inhale again without pinching off the balloon with their teeth, lips, or fingertips. This requires maintenance of intra-abdominal pressure to allow inhalation through the nose without the air coming back out of the balloon and into the mouth.

The authors of this clinical suggestion hypothesize that the resistance of the balloon during exhalation requires an increase in abdominal musculature activation and therefore the ability of the abdominals to oppose the diaphragm and assist with maintaining an ideal ZOA may be enhanced. The activation/setting of the abdominals pulls the lower ribs down and in (caudad and posterior) and helps to inhibit/relax the paraspinals muscles (trunk extensors) which may help to decrease the patient/athlete’s lumbar lordosis and pain in the paraspinal region through reciprocal inhibition. The abdominals do not produce any appreciable torque or motion in the spine and are functioning in this case as stabilizers of the ribs during breathing, not as prime movers. The rib motion (depression/caudad/posterior) optimizes the ZOA.

When the exercise is performed by the patient/athlete with hamstring and gluteus maximus (glut max) activation (hip extensors) the pelvis moves into a relative posterior pelvic tilt and the ribs into relative
mechanical advantage than the glut max for hip extension because of the increased lever arm (distal attachment site on the tibia which is more distal than the glut max’s distal attachment site which is on the femoral shaft). The glut max is a powerful muscle for hip external rotation because of the oblique fiber orientation. Because the diaphragm and psoas pull less up and forward (cephalad and

**Figure 3. Instructions for Performance of the 90/90 Bridge with Ball and Balloon:**

1. Lie on your back with your feet flat on a wall and knees and hips bent at a 90-degree angle.
2. Place a 4-6 inch ball between your knees.
3. Place your right arm above your head and a balloon in your left hand.
4. Inhale through your nose and as you exhale through your mouth, perform a pelvic tilt so that your tailbone is raised slightly off the mat. Keep low back flat on the mat. Do not press your feet into the wall, instead pull down with your heels.
5. You should feel the back of your thighs and inner thighs engage, keeping pressure on the ball. Maintain this position for the remainder of the exercise.
6. Now inhale through your nose and slowly blow out into the balloon.
7. Pause three seconds with your tongue positioned on the roof of your mouth to prevent airflow out of the balloon.
8. Without pinching the neck of the balloon and keeping your tongue on the roof of your mouth, inhale again through your nose.
9. Slowly blow out as you stabilize the balloon with your left hand.
10. Do not strain your neck or cheeks as you blow.
11. After the fourth breath in, pinch the balloon neck and remove it from your mouth. Let the air out of the balloon.
12. Relax and repeat the sequence 4 more times.

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anterior) and more down and forward (caudad and anterior) respectively on the spine via hamstring and abdominal co-activation, the diaphragm and spine are able to achieve an ideal position. (Figure 2) During the second inhalation (after exhaling into the balloon for the first time), an optimal position of the spine and diaphragm can be maintained via the opposition of the abdominals due to the back pressure in the balloon. This inhalation effort with the balloon in the mouth and the ribs in a depressed/externally rotated state will direct the air into the lungs to expand the apical area of the lungs, especially when an arm is raised above the head to help direct it there. When the ribs are held down and a second inhalation occurs, the surrounding soft tissue i.e. pectoralis muscle lengthens/stretches with chest expansion from air that fills the lungs as the distance between the pectoralis attachment on the ribs and sternum and on the humerus is increased. This apical chest wall expansion may be particularly beneficial for individuals with scoliosis, depressed shoulder girdles, or rounded shoulders.

The balloon resistance also requires more activation/contraction of the transversus thoracis (triangularis sterni) muscle which is active during forced exhalation.46 (Figure 4) Additionally, the respiratory cycle with resistance, also requires lengthening and contractions of both the internal and external intercostal muscles which are active for both phases of respiration.12

USE IN PHYSICAL THERAPY
Clinical experience with the BBE includes utilization of the exercise for both female and male patients (more females than males), ages 5-89 with a wide variety of diagnoses including: low back pain, trochanteric bursitis, SIJ pain, asthma, COPD, acetabular labral tear, anterior knee pain, thoracic outlet syndrome (TOS) and sciatica. Improved function and decreased pain has been noted with patients who were prescribed a BBE as part of their home exercise program in both published and non published cases. Published cases have included a female with right LBP and sciatica47 a male with thoracic outlet syndrome,48 a male with thoracic outlet syndrome,49 a female with scoliosis,48 a male with asthma,49 The female had 100% improvement in her function with an initial Oswestry Disability Index (ODI) score of 40% and a discharge ODI of 0%. This change exceeded the minimal clinically significant difference (MCSD) of 20%.50 Her pain level also improved from an initial score of 9/10 to a discharge score of 0/10. Again this response exceeded the MCSD for the numerical pain scale which is a 2.5.50 The patient with TOS also had remarkable improvement in his function and was able to avoid surgery and return to playing football. His initial Northwick Park Neck Pain Questionnaire51 was 55.5% and at discharge it was 0%. This far exceeded the MCSD of 5%.52 The goal for the male with asthma was to restore his ZOA with the BBE and manual restorative techniques. His spirometry scores improved from 1,800cc to 2,700cc on one visit and from 1,500cc to 3,200cc on a subsequent visit.49 No other outcome measures were used.
The value of the BBE can be discussed at an anecdotal level through written reports and personal experience. A story in the local Omaha, NE newspaper described the unusual training utilized by the University of Nebraska women's volleyball team. The training included the athletes blowing up balloons in order to relieve back and neck tension and prevent breath holding, both of which may restrict arm swing and reach. The training was directed by the physical therapist who developed the BBE, and currently serves as the biomechanical consultant to the University of Nebraska-Lincoln.

**DISCUSSION**

Despite the BBE's use for a variety of patient populations, there is little data published on the efficacy of such an exercise. O'Sullivan reported the need for rehabilitation of lumbar-pelvic instability that includes integration of the diaphragm, deep abdominals and pelvic floor. However descriptive studies to propose intervention strategies to integrate the diaphragm, deep abdominals and pelvic floor are lacking. Additionally, studies to investigate the efficacy of strategies are needed. The BBE is a specific example of an exercise that could be useful for integrating co-activation of deep abdominal muscles with pelvic floor and diaphragm during neuromuscular training and a wide variety of stabilizing maneuvers.

Lando et al. conducted a study of 25 subjects with severe chronic obstructive pulmonary disease (COPD) to investigate the influence of lung-volume reduction surgery on breathing. Lando et al. reported that the subject's ZOA of the diaphragm was increased as a result of the surgery which increased their exercise tolerance and breathing efficiency. This is one study that supports the value and benefit of obtaining optimal ZOA for breathing, which in this case was achieved via surgery. The asthma case report also supports the value of obtaining optimal ZOA for breathing which was achieved with conservative physical therapy techniques rather than surgery. The BBE is a conservative exercise intended to assist a patient/athlete in obtaining optimal posture and respiration and neuromotor control (lumbar-pelvic stability). However, the BBE has not yet been studied or tested experimentally.

Future studies of the effects of a single BBE and/or training effects of multiple BBE's could include EMG for abdominal muscle, spirometry for changes in breathing parameters, real time ultrasound for diaphragm length and/or changes in abdominal muscle thickness. Additionally, future studies designed to describe changes in pain and function attributable to the BBE are needed to investigate the clinical efficacy of this promising therapeutic exercise technique.

**ACKNOWLEDGEMENTS**

The authors wish to recognize Ron Hruska PT, MPA for his creative and innovative contribution to clinical care by developing the balloon blow exercise which has been used by thousands of clinicians and their respective patients/athletes.

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ABSTRACT

Eccentric exercise has been effectively used in the management of tendinopathies in multiple regions of the body. Lateral epicondylosis ("tennis elbow") is a common tendinopathy that has shown improvement following treatment utilizing isokinetic eccentric exercise. A novel exercise was developed for home-based eccentric exercise that has shown promise for use with patients with lateral epicondylosis. Clinicians should be aware of this exercise and consider it as an evidence-based intervention.

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Disclosure: Dr. Phil Page is employed by The Hygenic Corporation, manufacturers of the FlexBar®.
Therapeutic eccentric exercise (TEE) has been found to be an effective intervention for a variety of tendinopathies including Achilles tendinosis, shoulder impingement, and patellar tendinopathy. One of the first recommendations in the literature regarding the use of eccentric exercise for managing tendinopathies was made by Stanish et al in 1986. They suggested that eccentric exercise effectively “lengthened” the muscle-tendon complex resulting in structural remodeling of the tendon with hypertrophy and increased tensile strength of the tendon.

Eccentric exercise may also provide neuromuscular benefits through central adaptation of both agonist and antagonist muscles; therefore, TEE may provide both a structural and functional benefit during tendinopathy rehabilitation. Interestingly, some patients with LE exhibit lowered pain pressure thresholds (PPT) and larger referred pain patterns than would occur solely due to the presence of trigger points, suggesting a central nervous system mediation of pain. Many questions remain as to the mechanism of the effectiveness of TEE, as well as the appropriate dosage. In a recent systematic review, Woodley et al noted a lack of high-quality studies comparing the effectiveness of eccentric exercise to standard management of tendinopathies.

Subsequent to the Woodley et al review, clinical researchers at the Nicholas Institute for Sports Medicine and Athletic Trauma developed a novel eccentric exercise using a flexible rubber bar (FlexBar®, The Hygenic Corporation, Akron OH) for patients with LE. The researchers noted the previously described efficacy of eccentric training in LE patients using an isokinetic dynamometer in a study by Croisier et al, but wanted to develop an effective, cost-effective home-based eccentric exercise for their patients. This resulted in the creation of the novel FlexBar® exercise sequence (also known as “The Tyler twist”) shown in Figure 1.

In the prospective, randomized, quasi-control study, 22 LE patients were assigned to either a standard physical therapy (PT) treatment group (control) or a group that received standard PT with the addition of the novel FlexBar® exercise. There was no significant difference between the groups prior to the intervention. Standard PT included stretching, cross-friction
Figure 1. Instructions for the 5 Steps of the Exercise:
A. Hold FlexBar® in involved (right) hand in maximum wrist extension
B. Grab other end of FlexBar® with uninvolved (left) hand
C. Twist FlexBar® with noninvolved wrist while holding the involved wrist in extension
D. Bring arms in front of body with elbows in extension while maintaining twist in FlexBar® by holding with noninvolved wrist in full flexion and the involved wrist in full extension
E. Slowly allow FlexBar® to ‘untwist’ by allowing involved wrist to move into flexion (ie, eccentric contraction of the involved wrist extensors).
Inexpensive treatment as compared to clinically-based use of more expensive isokinetic devices. Tyler et al utilized the scientific inquiry process in order to answer the question of efficacy of this novel exercise intervention in a clinical setting.

There were some limitations to the Tyler et al study such as a small sample size. Only 21 of the 30 subjects needed for sufficient power completed the study. The researchers who performed that study noted significant improvements in the experimental group and therefore decided to terminate the random group allocation due to the ethical possibility that an effective treatment may have been withheld from the control subjects. The Tyler et al study only examined and reported short-term improvements; longer-term outcomes would help determine if the positive results were sustained over longer time periods. Nonetheless, the amount and variety of short-term improvement in symptoms described in the study seem to offer positive clinical benefits.

In today’s world of the Internet and social media, there were some interesting phenomena that resulted from this study. Within a year after the study, there were over 180,000 views of the “Tyler Twist” exercise video on YouTube. After presenting the abstract at the 2009 American Orthopaedic Society for Sports Medicine’s Annual Meeting, a press release was issued by the society. The New York Times, among other media outlets, posted blog articles about the results of the study, resulting in numerous replies from consumers. Patients provided impressive testimonials about their successes with the exercise. In addition, patients began asking about the possibilities of treating ‘golfers elbow’ with the same device, which has resulted in a similar ongoing clinical investigation.

In conclusion, this clinical suggestion demonstrates an excellent example of true “evidence-based practice” in physical therapy. By understanding the evidence and applying experience within a clinical environment, clinicians can develop effective, novel interventions. It also supports the scientific process used in clinical practice: developing a hypothesis based on a clinical need and testing it in a real-world, clinical situation, with real patients. Finally, today’s Internet-based society will continue to challenge rehabilitation providers to support and participate in

**DISCUSSION**

This clinical suggestion presents an excellent example of clinical practice leading to the creation of an evidence-driven novel exercise technique. Clinicians understanding the positive effects of eccentric exercise on tendinopathies used an existing clinical tool (the FlexBar®) to develop an “evidence-led” intervention that could be applied in today’s outpatient physical therapy environment. This clinical suggestion promotes an emphasis on home-based,
evidence-based practice as patients learn about successful treatments and look to their physical therapists to provide them.

Note: For a video demonstration of the exercise, visit http://www.youtube.com/watch?v=gsKGbqA9aNo

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