ABSTRACT

Purpose/Background: Specific movement patterns have been identified as influential in ACL injury; however, several key kinematic variables that might be predictive of future performance have not been fully investigated. The purpose of this research was to: 1) determine if subjects with ACL reconstruction display different displacement, velocity, and time to peak ground reaction force (GRF) during cutting activities than healthy subjects, 2) observe if subjects with visual disruption display differences in these variables, and 3) determine if visual disruption alters these variables in subjects with ACL reconstruction relative to healthy subjects.

Methods: Seventeen healthy female subjects and 17 female subjects with unilateral ACL reconstruction (ACLR) performed 40 trials of a cutting movement during which knee position was measured via a 3D electromagnetic system. Visual conditions were randomized to disrupt vision for 1 second as the subject began the cutting movement, or allow full vision for movement duration. Independent variables were lead/push off leg (ACLR limb or healthy non-dominant limb) and vision (disrupted or full). 2-way ANOVAs were utilized to determine differences between knee kinematics using dependent variables of displacement (m), absolute velocity (m/sec), and time to reach peak GRF (% of cut).

Results: Knee displacement was significantly less for ACLR (76 ± 11; 75 ± 16) than non-dominant (85 ± 08; 87 ± 12). Knee velocity was significantly slower for ACLR (81 ± 14; 84 ± 16) than non-dominant (92 ± 11; 97 ± 14). A significant interaction was noted for displacement and average velocity (p < .05). Time to reach peak GRF was significantly longer for ACLR (79.41 ± 2.28) than non-dominant (76.65 ± 4.41).

Conclusions: Subjects with ACLR displayed less knee displacement, slower velocity, and an increased time to reach peak GRF relative to healthy subjects' non-dominant knee. Visual disruption appeared to have some effect on movement, as noted by interaction effects. These movement adjustments may be indicative of an altered motor program that allows for successful and safe task completion while reducing the forces and load on the knee.

Level of Evidence: Level 2

Key Words: ACL reconstruction, Female, Kinematics, Lower extremity, Movement patterns

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INTRODUCTION

Non-contact ACL injuries frequently occur in females. Females participating in sports that include pivoting and jumping maneuvers suffer 4-to-6-times greater rates of ACL injury than their male counterparts.1 Many studies have investigated why female athletes incur a disproportionate number of ACL injuries. Much of the literature has focused on neuromuscular and biomechanical factors. Increasing evidence suggests that poor or abnormal neuromuscular control of lower extremity biomechanics, especially during athletic maneuvers such as cutting and landing, is a major contributor to the mechanism of non-contact ACL injury.2,3 The ACL may experience potentially dangerous forces during landing and twisting if the muscles controlling the knee do not sufficiently dissipate the forces and torques.

Known biomechanical and neuromuscular risk factors include the following for females: greater knee valgus angles and moments during cutting, landing, and squatting tasks;4,5 decreased knee flexion angles and knee flexion stiffness5 during cutting tasks; and greater hip adduction angles during a variety of activities.7,8 Other important findings include that there is an association between hip transverse and frontal plane angles and knee valgus moments during cutting tasks4,9 and that knee frontal and sagittal plane moments at both slow and fast speeds are influenced by the ability to preplan movement as opposed to making an unanticipated cutting maneuver.10,11

Hiemstra et al., Mackey et al., and Mattacola et al. demonstrate that ACL reconstructed subjects produced significantly less extension and/or hamstring torque on their reconstructed leg than their uninjured leg even up to 18 months post-surgery.12,22,42 Even greater knee extension and hamstring strength deficits have been noted when the ACLR knee is compared to the knees of uninjured peers rather than their non-surgical limb.12 The greater difference between the uninjured control group and the subjects with ACL reconstruction suggests a negative effect of the surgery on the contralateral limb or perhaps the presence of a previous deficit, thus implying that it should not be used as the only comparison limb.12,13 Paterno, Ford, Myer, Heyl, and Hewett14 support the existence of limb asymmetries in the lower extremities of ACLR patients during landing and jumping two years following ACL reconstruction.

Okuda et al. and Ferber et al. also suggest that proprioceptive dysfunction may occur secondary to ACL injury and reconstruction along with disruption and/or changes in movement patterns during gait and other simple activities.15,20 When athletes move their lower extremities, they are constantly interacting with their environment, often with large resultant impact forces. The central nervous system modulates and controls movement with input from receptors and vision. If there is a mismatch between what the athlete anticipates and how they react, the potential for injury increases. Vision is expected to play a large role in the ability to adapt to various environments; however this may not be the case. Research suggests that continual visual input to complete tasks successfully may not be necessary; especially when falls or movements are self-initiated.17 Unexpected falls display different muscle activation patterns and ground reaction forces (GRF). It appears that having an internal representation of the task requirements allows subjects to respond similarly to the task as if vision was present.17

The intent of this current investigation was to fill a gap in the literature regarding reliance on sensorimotor and visualmotor systems for movement of subjects with ACL reconstruction performing an athletic, functional-type activity. Given that athletes rely not only on the somatosensory system to provide feedback to stabilize their system, but also upon their visual and vestibular systems, it is important to study what would happen if one of these systems were not allowed to have an influence. The authors of the current study are unaware of any research that attempts to mimic an athletic situation while inducing a temporary loss of vision in subjects with ACL reconstruction. Requiring subjects to incur a distraction, such as catching a ball, just prior to movement and move into an unplanned direction while denying vision during a certain phase of movement should produce different and perhaps faulty movement patterns in those with ACL reconstruction compared to healthy subjects. The purpose of this research was to 1) determine if subjects with ACL reconstruction display different knee displacements, velocities, and time to peak GRF during cutting activities than
healthy subjects, 2) observe if subjects with visual disruption display differences in these variables than with vision available, and 3) determine if visual deprivation alters these same variables in subjects with ACL reconstruction more significantly than in healthy subjects. Additionally, limb to limb comparisons will be completed within the ACLR group and healthy group to determine whether asymmetries exist between surgical and non-surgical or dominant and non-dominant extremities, respectively.

METHODS

Subjects
Thirty-four female volunteer subjects between the ages of 18 and 45 years, 17 subjects with unilateral ACL reconstructions and 17 control subjects with no recent history of knee problems were recruited for this study. Subjects were recruited from the University of Minnesota and metropolitan area athletic performance training centers. This age range was utilized to enhance subject recruitment, keeping in mind that differences may be inherent within this age group. However, only two of the subjects were between the ages of 35 and 45. These subjects demonstrated equivalent activity levels as the younger subjects. Inclusion criteria required that subjects with ACL reconstruction met the following: (a) diagnosis of complete ACL rupture, with no severe or complex meniscus or collateral ligament damage or continued knee dysfunction; (b) subsequent unilateral ACL reconstruction (average duration post-operatively was 4.6 years); (c) female, age 18-45; (d) no history of visual, vestibular, or neurological problems; (e) no knee pain, effusion (within 2 cm measured at the joint line as compared to the opposite side was considered acceptable) or back pain that necessitated care by a physician. All subjects completed an informed consent process approved by the Institutional Review Board at the University of Minnesota to participate in the study. Subjects also signed the University of Minnesota Academic Health Center’s Authorization for Photography, Filming, or Interviewing because all trials were videotaped and linked to the Motion Monitor system for review and data reduction.

Instrumentation
Three-dimensional lower extremity kinematic data was collected using The Motion Monitor integrated system (Innovative Sports Training, Inc., Chicago, IL) with Ascension’s Flock of Birds electromagnetic motion capture system (Ascension Technology Corporation, Burlington, VT). The reliability and validity of electromagnetic motion capture systems in gathering 3-D movements has been previously documented as acceptable.20,21,22,23,24,25 A Bertec force plate (Bertec Corporation, Columbus, OH) was linked to the Motion Monitor system through an A/D interface panel (Measurement Computing’s PCIM 1602) for measurement of ground reaction forces. A T- Bayonet Neill-Concelman Connector adaptor allowed another connection to an Analog to Digital conversion (A/D) board (National Instruments Corporation, Austin, TX) to trigger the shutter glasses mechanism (Durfee Design, Minneapolis, MN/VRex, Hawthorne, NY) to disrupt vision. A second connection off the separate A/D board was connected back to the Motion Monitor A/D interface panel to pick up the voltage drop when the glasses shuttered down. These shutter glasses allowed full vision in the open position, but were capable of being triggered at pre-selected phases of movement (based on force plate data) to shut down and block vision from anywhere between 0.1–2.0 seconds by a
LabVIEW program set up on a computer that was also connected to the external A/D board via a Peripheral Component Interconnect (PCI) card. Adjustable parameters available on this program included percentage of bodyweight to trigger vision disruption and duration subject cannot see. Another computer was used to trigger a high or low tone indicating which direction the subject needed to cut. This computer was linked to the Motion Monitor system to allow for data capture of the sound impulse. Processing of kinematic and kinetic data was performed by The Motion Monitor software (Innovative Sports Training, Inc., Chicago, IL).

Procedures
Leg dominance was determined by asking each subject to pretend to kick a ball. The leg self-selected by the subject was assigned as the dominant leg for the remainder of the study. For kinematic assessment, electromagnetic sensors were affixed to the skin with double-sided adhesive tape to both the posterior head via attachment to a thermoplastic molded headband and at sacral level two. Four other sensors were attached to each distal lateral thigh near the iliotibial band (ITB) and to the mid shank of each tibia. To determine the local coordinate system, anatomic bony landmarks on the pelvis, thigh, and shank were digitized for data capture of lower extremity movement using International Society of Biomechanics (ISB) recommendations for the hip and ankle and Grood and Suntay recommendations for the knee. The Lardini method was used to determine the location of hip joint centers. The local coordinate system for the pelvis was determined using points on the ASIS and PSIS; the thigh was set up using the greater trochanter and medial/lateral femoral epicondyles; and the shank was determined using lateral/medial epicondyles, medial and lateral malleoli, and medial/lateral joint lines. The global reference system was defined using the right hand rule for all body segments with the positive x-axis defined as the posterior to anterior axis, the positive z-axis defined as the inferior to superior longitudinal axis, and the positive y-axis as right to left. See Figure 1 for sensor placement.

The task consisted of an open cutting maneuver from a static athletic stance position. Subjects stood on a force platform with equal weight bearing across limbs. When ready, a ball was pitched from an automatic pitching machine directly to the subject from a distance of 15 feet. On the count “one and two and,” a high or low pitch tone was heard in the headphones, indicating which direction the subject was to cut. Visual conditions were randomized so that the glasses either disrupted vision for one second as the subject began the cutting movement, or remained open for the duration of movement. This duration was determined through pilot testing to ensure that visual disruption was of sufficient length to last the entire cutting motion. The timing was consistent subject to subject. Subjects were instructed to catch the ball and cut immediately to the direction indicated by the tone. A taped line angled at approximately 40 degrees to the right and left was secured on the testing platform to guide subjects. This angle is in accordance with values typically seen in a sporting context. Subjects were instructed to cut along the line of tape at a distance that was comfortable for them. See Figure 1 for the laboratory set up with a subject in ready position.
Data was captured at 100 Hz and low pass filtered at 30 Hz using a Butterworth 4th order zero phase shift filter. Force plate data was sampled at 1000 Hz with an analog anti-aliasing filter of 500 Hz. Given the speed of the cutting movement, the shutter glasses were triggered to close during movement at a point when the force plate was unloaded at 5% of the subject’s bodyweight or conversely when the weight of the subject was 95% of their maximum body weight as measured during calibration of the LabVIEW shutter glass program. The glasses shuttered down and remained off for one second. Subjects performed five practice trials to gain familiarity with the task and equipment worn during testing. Data was analyzed for the movement interval for which vision was disrupted and compared to the same interval of movement when vision was available for all variables except time to reach peak GRF. The entire movement was used for that analysis. Subjects completed 40 successful cutting trials in total, randomized for direction and vision, resulting in 10 trials for each condition. Typical duration between trials was two minutes, which allowed sufficient rest time.

Data Processing
Final outcome variables included: absolute knee displacement, peak and average absolute knee velocities, and time to peak GRF as a percentage of cutting movement. Peak absolute knee displacement was determined by using $x$, $y$, and $z$ components of displacement and was descriptive of the overall movement of the knee joint in length from start to finish of the resultant vector. Peak and average knee absolute linear velocities used $x$, $y$, and $z$ components of velocity data and were descriptive of how fast the knee joint movement occurred along the resultant vector. Time to peak force was converted to a percent of cutting movement for normalization and gave an indication of push off capability from the force plate during the cutting activity.

Statistical Analysis
Based on the lowest estimation of effect size of all variables (.60), power analysis of pilot data determined that a sample size of 17 per group, for a total of 34 subjects, was necessary to achieve sufficient power. Independent variables included knee (ACL reconstructed, healthy non-dominant) and vision (full vision, disrupted vision). The non-dominant limb of the healthy group was matched to the surgical limb of the ACLR group based on the fact that the majority of the surgical limbs were stated as non-dominant by subjects. Two separate 2 x 2 repeated-measures analysis of variance were conducted to compare knees and vision for displacement, velocity, and time to peak GRF. Two separate analyses were necessary given in a cutting movement there is a lead leg and push off leg that requires analysis. Post-hoc Tukey tests were conducted for multiple comparisons of all pair-wise differences. A two-way repeated measures ANOVA was also used to analyze the limbs within the ACLR group and within the healthy group. Kruskal-Wallis non-parametric testing was completed for those variables that violated normality. A critical level of $p < 0.05$ was considered statistically significant for all other group analyses. Figure 2 displays the study design schematic.

RESULTS
These results are part of a larger study that included analysis of other variables. Overall, subjects with ACL reconstruction self-reported high functioning, describing good to excellent ratings on average on the Cincinnati Knee Rating Scale (CKRS). Subjects with ACLR also described mostly normal/unlimited activity levels (12/15) and a patient grade of 8.4/10 on the CKRS, indicating good to excellent overall knee ratings at the time of testing. Healthy subjects also described their activity levels as recreationally active and athletic on a consistent basis. Descriptive and clinical data are presented in Table 1 and Table 2. No significant differences existed between the ACL and healthy group for cut length of either leg when standardized to height, and was therefore not

Figure 2. Schematic of study design for repeated measures analysis of variance (ANOVA).
influential on the outcome of other analyses. Body weight was significantly different between groups, with healthy subjects weighing less. This may have impacted results; therefore a Pearson Product-Moment correlation was completed to identify any significant relationships between body weight and dependent variables. No variables reported here displayed a significant correlation with bodyweight.

**ACL Reconstructed Limb vs. Healthy Non-Dominant Limb**

**Lead Leg.** Analysis between subjects with ACL reconstruction leading the cut with their reconstructed limb and healthy subjects leading with their non-dominant limb demonstrated a significant main effect for displacement ($p=0.01$), peak velocity ($p=0.01$) and average velocity ($p=0.01$). For this cutting movement with the reconstructed or non-dominant limb as the lead leg, the ACL reconstructed limb displayed significantly shorter displacement and slower peak and average velocities relative to the non-dominant limb of the healthy group. The ACLR group also reached their peak GRF later in the cutting movement ($p=0.06$), however, this was not statistically different; rather it displayed a trend toward significance (Table 3).

**Push Off Leg.** For the cutting motion with subjects with ACL reconstruction pushing off with their reconstructed limb and healthy subjects pushing off with their non-dominant limb, significance differences were present for displacement ($p=0.01$) and average velocity ($p=0.02$). Percent of cutting movement to reach peak GRF occurred significantly later in the cutting movement for the ACLR group during this movement as well ($p=0.03$). Consistent with previous results, the ACL reconstructed limb displayed shorter displacement, slower average velocity, and reached their peak GRF later in the cutting movement (Table 3).

### Table 1. Demographic data for healthy subjects ($n=17$) and subjects with ACL reconstruction ($n=17$).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Healthy Subjects Mean (±SD)</th>
<th>ACL Subjects Mean (±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>25.3 (6.0)</td>
<td>26.5 (6.3)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.68 (.06)</td>
<td>1.70 (.07)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>59.6 (5.72)</td>
<td>66 (6.44)*</td>
</tr>
<tr>
<td>KT Change (mm)</td>
<td>0.90 (0.74)</td>
<td>1.70 (0.97)*</td>
</tr>
<tr>
<td>Cut Length (m)</td>
<td>0.38 (0.07)</td>
<td>0.36 (0.08)</td>
</tr>
<tr>
<td>Limb Dominance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>16 subjects</td>
<td>17 subjects</td>
</tr>
<tr>
<td>Left</td>
<td>1 subject</td>
<td></td>
</tr>
</tbody>
</table>

* $p < 0.05$

### Table 2. Additional descriptive data for subjects with ACL reconstruction.

<table>
<thead>
<tr>
<th>ACL Reconstructed Limb</th>
<th>Lead Leg</th>
<th>Push Off Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw</td>
<td>4 subjects</td>
<td>4 subjects</td>
</tr>
<tr>
<td>Left</td>
<td>13 subjects</td>
<td>13 subjects</td>
</tr>
<tr>
<td>Type of Surgery</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PT</td>
<td>9 subjects</td>
<td>9 subjects</td>
</tr>
<tr>
<td>HS</td>
<td>7 subjects</td>
<td>7 subjects</td>
</tr>
<tr>
<td>Cadaver PT</td>
<td>1 subject</td>
<td>1 subject</td>
</tr>
<tr>
<td>Mean Years Post Surgery (SD)</td>
<td>4.6 (2.7)</td>
<td>4.6 (2.7)</td>
</tr>
<tr>
<td>Mean Limb Symmetry Index Triple Hop (SD)</td>
<td>95.8% (8.3)</td>
<td>95.8% (8.3)</td>
</tr>
<tr>
<td>Mean Limb Symmetry Crossover Hop (SD)</td>
<td>97.2% (10.8)</td>
<td>97.2% (10.8)</td>
</tr>
<tr>
<td>PT = patellar tendon, HS = Hamstring</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 1.** Demographic data for healthy subjects ($n=17$) and subjects with ACL reconstruction ($n=17$).

**Table 2.** Additional descriptive data for subjects with ACL reconstruction.
Disrupted Vision vs. Full Vision

No significant main effect occurred for vision when combining the ACL reconstructed and non-dominant limbs.

Group x Vision Interaction

ACL Reconstructed Limb or Non-dominant Limb as Lead Leg. A significant interaction was noted for displacement, with the non-dominant/full vision condition displaying a greater displacement than all other conditions (p = 0.01). A significant interaction was also noted for average velocity of the lead leg, with the non-dominant/disrupted and full vision conditions displaying a faster average velocity than the ACL/disrupted and full vision pairings (p = 0.004). A trend toward a statistically significant difference was noted for peak velocity, with the non-dominant/disrupted and full vision conditions displaying a faster peak velocity than the ACL/disrupted and full vision pairings (p = 0.05) (Table 4).

ACL Reconstructed Limb or Non-dominant Limb as Push Off Leg. The ACL/disrupted and full vision pairings reached their peak GRF sooner than the non-dominant healthy group with disrupted and full vision, however, this was not statistically different; rather it displayed a trend toward significance (p = 0.05) (Table 4).

Within Groups

ACL Reconstructed Limb vs. Non-Surgical Limb. Within the ACL reconstructed group, no significant differences existed between the ACL reconstructed knee and the non-surgical knee or between vision conditions for any variable. There were also no significant interactions.

Healthy Dominant Limb vs. Non-Dominant Limb. Within the healthy group only, the non-dominant limb as lead leg reached a significantly faster peak velocity than the dominant limb. This indicates that...
faster movement occurs in the lead leg when pushing off the dominant limb for the healthy subjects versus their non-dominant limb (p<.01) (Table 5). There was also a main effect of vision for displacement for lead and push off legs (p = 0.02; p = 0.02) and for average velocity of lead legs (p = 0.004). With vision disrupted, healthy subjects moved less distance and at a slower average velocity based on the data from their lead and push off legs (Table 6). There was also a significant interaction between the dominant and non-dominant limbs and visual conditions for average velocity of the lead leg during cutting (p = 0.04). Pushing off from the dominant limb with vision created a significantly faster lead leg than for other pairings. A trend towards a significant interaction also existed for absolute displacement, with pushing off the dominant limb with disrupted vision having the lower displacement for either leg relative to the same scenario with vision (p = .05) (Table 7).

**DISCUSSION**

The purpose of this study was to compare movement trajectories of the knee joint, as described by displacement, velocity, and percent of cut to reach peak GRF,
between female subjects' ACL reconstructed knees and healthy subjects' non-dominant knees when vision was disrupted or fully available during an 'unplanned' cutting movement and relate these findings to motor planning strategies. Previous research\cite{14, 25, 33, 34, 35} supports that specific alterations of angles, moments, and EMG patterns have an association with gait, landing, and cutting kinetics and kinematics in females, and subjects with ACL deficiency or ACL reconstruction. McLean et al., Ford et al., Sigward et al., and Besier et al. demonstrated that sidestep cutting maneuvers create kinematics and kinetics that place the knee in a vulnerable position, similar to the kinematics and kinetics suggested as possible mechanisms for ACL injury.\cite{3, 4, 8, 9, 10, 31} The integrity of the ACL during landing requires the proper coordination of lower extremity muscles, especially the quadriceps and hamstrings.\cite{32} Decreased knee flexion and trunk flexion, increased knee valgus angles and moments, increased latency of hamstrings, and increased quadriceps activity are common findings relating to the possible mechanisms for increased incidence of ACL injury and subsequent deficiency and/or surgical reconstruction.\cite{14, 25, 33, 34, 35}

A limited number of studies\cite{36, 37} have compared the velocity of subjects with ACL reconstructed or deficient knees compared to controls, and only in a general sense. None have looked at the absolute displacement and velocity of the knee joint as was identified in this research. Rather, the few\cite{36, 37} that did simply measured the velocity of movement of the body, i.e. walking or running velocities; or indirectly inferred velocity from measures of other data. In these studies,\cite{36, 37} the subjects with ACL reconstruction consistently moved at slower velocities than the healthy control subjects. When comparing the ACL reconstructed and healthy non-dominant knees during a cutting movement in this research, displacement and velocity measures consistently displayed significant differences. Regardless of whether the analyzed limb was pushing off or leading, when compared, the ACLR subjects had less displacement and slower velocities than the healthy subjects. Previously authors have suggested that changes in joint kinematics and kinetics following ACL reconstruction, like reducing velocities of movement, are common adaptations to protect the knee.\cite{36, 37} The faster one travels to eventually collide with a stable surface and stop, the higher the GRF and the more the neuromuscular system must actively dampen these forces. This requires sufficient strength and neuromuscular coordination.\cite{38} Reducing velocity will help to reduce the GRF upon landing.\cite{17, 33, 38, 39, 40, 41} This reduction in velocity and distance traveled may be an alteration in movement that reduces their risk and allows for safe completion of the task.

A major component of this research was to identify how well subjects moved into the cutting maneuver. The variable used to capture this concept was the percent of full cutting movement that subjects needed to reach their peak GRF. Each trial was normalized to 100 percent because the duration of each cut was different for each trial and subject. This variable mostly gave an indication of the push off leg's ability to generate force and power when an audible tone sounded to signal the subject to initiate the cut. Sidestep cutting in sports is used as an evasive maneuver at variable speeds. Cutting movements require the integration of several systems for successful performance. Sufficient propulsion and stabilization of the push off leg is necessary to move the lead leg and rest of the body through space. The lead leg must also anticipate the landing by activating specific muscles in a specific sequence to minimize impact forces with the ground.

Consistent significant differences existed between the ACLR group and healthy group in ability to reach their peak ground reaction force quickly. Subjects with ACL reconstruction were slower to reach their peak GRF. These results may relate to other research findings reporting that the involved surgical limb showed reduced ability to generate force at takeoff during a drop vertical jump, whereby female athletes displayed side-to-side differences during both the landing and takeoff phase of the drop vertical jump two years later, with the ACL reconstructed limb displaying reduced abilities to accept load quickly on landing and to generate force upon takeoff.\cite{14} Other factors that may impact this variable are lower extremity strength, power, neuromuscular coordination, and proprioception. If reduced, as is frequently demonstrated by subjects with ACL reconstruction, subjects may struggle with achieving peak force quickly,\cite{42} which may also be reflected in reduced displacement and velocity. Increasing evidence suggests that poor
or abnormal neuromuscular control of lower extremity biomechanics, especially during athletic maneuvers such as cutting and landing, is a major contributor to the mechanism of non-contact ACL injury in females.\textsuperscript{2,3} Increased knee valgus angles and moments, reduced knee flexion angles and increased hip adduction angles all may influence movement patterns in a negative manner that may result in the differences noted between the ACLR group and healthy group of females in this research. Research also suggests that females are weaker than males in measurements of hip strength as well as quadriceps and hamstring strength, even when normalized to body weight.\textsuperscript{34} Females exhibit different lower extremity muscle activation patterns than males, with hamstrings demonstrating a delay in activation relative to the quadriceps.\textsuperscript{9,34} Muscle activation also differs during anticipated and unanticipated tasks, where unanticipated events create muscle activation patterns that may be detrimental and increase injury risk.\textsuperscript{3,6,8,10,11} Therefore, coupling ACL reconstruction with the female gender may increase the strength deficits and dysfunctional neuromuscular patterns noted, given that hip and thigh strength reductions and neuromuscular alterations have been noted in subjects with ACL reconstruction.

Proprioceptive deficits may still persist after ACLR and subsequent rehabilitation; however this cannot be stated definitively in this group of subjects, as it was not tested directly. The subjects push off leg functions essentially in single leg stance as the lead leg is lifted upon movement into the cutting motion. If proprioception is compromised, subjects may have less stability on that leg which would impact their ability to generate force for push off.\textsuperscript{15} With disruption of the ACL and surrounding tissue, sensory input is altered, affecting proprioception and muscle activation patterns.\textsuperscript{5,16} Research suggests that proprioceptive dysfunction may occur with ACL injury and reconstruction along with disruption and/or changes in movement patterns during gait and other simple activities.\textsuperscript{15,16} Thus, for these subjects with ACL reconstruction, taking longer to reach their peak GRF could be reflective of reduced lower extremity strength, power, altered biomechanics, neuromuscular control, or proprioception. Overall, the data from the current investigation showed differences which suggest that subject’s strength, timing, and power may be reduced, thus resulting in a decreased ability to generate lower extremity force.

An interesting observation was that healthy subjects demonstrated greater standard deviations across all conditions for percent of cut to reach peak GRF than subjects with an ACL reconstruction. They also demonstrated significant differences between their legs, whereas the ACLR group did not. When comparing the subjects with ACLR separately and analyzing leg-to-leg differences, the ACLR group displayed no significant differences between pushing off with their ACL limb and pushing off with their non-surgical limb. Given these results, it appears that the ACL reconstruction had an impact on movement bilaterally relative to the healthy group. This is demonstrated by the differences between the ACLR group and healthy subjects, yet a lack of differences between the ACL reconstructed limb and non-surgical limb of the ACL subjects. This finding is supported by other studies that suggest that ACL injury and subsequent reconstruction affects both limbs.\textsuperscript{7,12,14}

Within the healthy group, visual disruption did have an impact on knee displacement of the push off limb. The combination of group and vision also had some affect on displacement and peak velocity. Most often the dominant limb reached a faster velocity or had a greater displacement with vision. Average velocity was very close to showing a trend in the same direction at $p$ value of 0.08. This may be suggestive of more variability across trials for healthy subjects, which is more likely to occur for this healthy group based on recent research findings that variability is a necessary component of healthy movement patterns, while a reduction in variability may increase injury risk due to altered motor planning and control.\textsuperscript{43,44,45,46,47,48} Some variability in movement is necessary for reduction of injury risk. Rigid movement patterns may result in the inability to adjust to complex tasks, which may increase injury risk. It may be that a person with an injury and/or surgery pays more attention to their movement to ensure safe and effective completion of the task, thus repeating the same pattern of movement throughout trials.

Given the results of this research, continual visual input may not be necessary to complete tasks successfully, even when proprioception may also be
compromised due to injury/surgery. Given no main effect for vision, these findings support previous research\textsuperscript{17,38,40} that periodic visual access to the environment and task is sufficient for completion of the task by adoption of a new or different ‘default’ motor program. It is also possible that subjects may have a visual representation of the task which is transformed into movement either directly or via kinesthetic representation, which may be required for more complicated movements or when the visual representation is lost or disrupted.\textsuperscript{49} Despite the task being somewhat unplanned with several distractions, it must be considered that the task may be a familiar and simple movement pattern for some subjects. Lieberman and Hoffman demonstrated that subjects with more experience in a task respond with less difference in movement patterns when vision is disrupted.\textsuperscript{50} The results of this present study are consistent with the findings of Lieberman and Hoffman.\textsuperscript{50}

To perform everyday movements and interactions, the central nervous system modulates forces before contact with a landing surface, as well as through the time course of the movement. Controlling an expected collision with the landing surface requires some prediction to anticipate the GRFs that will occur upon impact.\textsuperscript{17} Other aspects of movement can make this more complicated given the wide variety of task conditions that occur, such as velocity of movement, landing surface, height of drop, or range of movement required. These task constraints can result in larger forces and could lead to serious injury if adaptations are not correctly estimated.\textsuperscript{17} Thus, continuous vision and predictive control mechanisms has been purported as important for successful and safe task completion. However, this research and results reported by others\textsuperscript{17,38,40} suggest that the role of vision is not quite as important as originally thought. When subjects are able to visualize the task and environment and perform it with vision, when the time comes to perform the task without vision, minimal EMG, kinematic and kinetic changes occur that are different from when vision was available.\textsuperscript{17,38,40} Thus in trials where vision was not available, it is possible that vestibular, proprioceptive, and cognitive input all interact in a way to allow for control of movement during the task from beginning to end with minimal change. For subjects with ACL reconstruction, this results in moving in a more rigid pattern that reduces their risk. For the healthy subjects, the result was greater variability in their movements in order to accommodate each situation.

There are several limitations to this study. The use of surface electromagnetic sensors mounted on the skin may allow for skin slippage with movement. Every attempt was made to keep the skin motion artifact low; however slight movement may have occurred. In an attempt to keep this low, sensors were placed on areas that had less underlying muscle or tissue movement. Also, for the calculated variables in this research, movement of the tibia relative to the femur was not used, thus the precision of the electromagnetic sensors in capturing underlying bone motion may not be as important. The pertinent data used was a point within the knee joint moving through space. Also, this surface-based sensor error is usually not systematically different between groups so that the distribution of error should be similar between the two study groups. Also, despite finding significant differences between groups and in combination with visual disruption, confirmation of whether these differences are clinically significant is uncertain.

Time after surgery may be another limitation. ACL subjects were an average of 4.6 years after surgery with a range from barely one year to nine years. This range is quite broad and may be a limitation to the study, in that subjects closer to their ACL reconstruction may have demonstrated more significant differences in movement variables from healthy subjects as compared to those with more time between ACL reconstruction and testing. Narrowing this range would allow for more specific understanding of movement patterns during specific times after ACL reconstruction, especially times when subjects are thought to be more vulnerable to re-injury. Type of ACL surgery was variable as well, which may have implications on outcomes as hamstring and patellar tendon grafts may exhibit different deficits at different follow up periods. The final limitation was the lab environment. The lab set up was such that subjects were unable to run or move into a cutting maneuver and had to start from an athletic stance. This may have been too simplistic to identify many differences between groups. Having the ability to run and cut obviously simulates an athletic maneuver more realistically.
CONCLUSION

This research examined movement patterns of the knee joint during unplanned side-step cutting maneuvers of subjects with ACLR and healthy subjects with random instantaneous vision disruption. Movement patterns were analyzed in new and unique ways relative to what had been reported in much of the research on ACL injury and movement. Previous findings\textsuperscript{14,34,35,42} may help to explain the movement variations between subjects with ACLR and healthy subject non-dominant knees; i.e. less postural stability and strength of the ACL reconstructed limb may result in an increased time to reach peak GRF and reduced velocity of ACL reconstructed subjects during cutting. With visual input changes (when vision was disrupted), subjects demonstrated minimal changes to their patterns of movement, thus were most likely relying on an internal visual memory of the environment and task characteristics to perform the movement successfully. However, it does appear that a few consistent pattern changes were noted when vision was disrupted. Lack of vision resulted in reduced absolute velocity and displacement, especially for subjects with ACL reconstruction, thus suggesting use of a new or altered ‘default’ motor program. Implications for rehabilitation of patients with ACL reconstruction are inherent in the outcomes of this research given the notable changes in displacement, velocity, and time to reach peak GRF relative to the healthy group. Working on velocity of movement and single leg push off skills would be helpful to improve performance in athletic situations. Knowing that these skills are lacking even over four years after surgical reconstruction indicates areas to consistently focus on athletically to improve performance and reduce injury risk. Rehabilitation programs and skill training may benefit from the addition of activities where vision is disrupted to further challenge patients. Overall, this study provides indirect information related to strength, proprioception, power, visual guidance of movement, motor planning, and ACL reconstruction that may affect rehabilitation program development.

REFERENCES


15. Okuda K, Abe N, Katayama Y, Senda M, Kuboda T, Inoue H. Effect of vision on postural sway in


ABSTRACT

Purpose/Background: Historically, patellofemoral pain syndrome (PFPS) has been viewed exclusively as a knee problem. Recent findings have suggested an association between hip muscle weakness and PFPS. Altered neuromuscular activity about the hip also may contribute to PFPS; however, more limited data exist regarding this aspect. Most prior investigations also have not concurrently examined hip and knee strength and neuromuscular activity in this patient population. Additional knowledge regarding the interaction between hip and knee muscle function may enhance the current understanding of PFPS. The purpose of this study was to compare hip and knee strength and electromyographic (EMG) activity in subjects with and without PFPS.

Methods: Eighteen females with PFPS and 18 matched controls participated in this study. First, surface EMG electrodes were donned on the gluteus medius, vastus medialis, and vastus lateralis. Strength measures then were taken for the hip abductors, hip external rotators, and knee extensors. Subjects completed a standardized stair-stepping task to quantify muscle activation amplitudes during the loading response, single leg stance, and preswing intervals of stair descent as well as to determine muscle onset timing differences between the gluteus medius and vastii muscles and between the vastus medialis and vastus lateralis at the beginning of stair descent.

Results: Females with PFPS demonstrated less strength of the hip muscles. They also generated greater EMG activity of the gluteus medius and vastus medialis during the loading response and single leg stance intervals of stair descent. No differences existed with respect to onset activation of the vastus medialis and vastus lateralis. All subjects had a similar delay in gluteus medius onset activation relative to the vastii muscles.

Conclusion: Rehabilitation should focus on quadriceps and hip strengthening. Although clinicians have incorporated gluteus medius exercise in rehabilitation programs, additional attention to the external rotators may be useful.

Level of Evidence: 4

Key Words: gluteus medius, knee, patella, surface electromyography

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INTRODUCTION

Patellofemoral pain syndrome (PFPS) is a common problem experienced by active adults and adolescents; however, its etiology has remained vague and controversial. Often times, patients complain of diffuse peripatellar and retropatellar pain that may limit their ability to perform activities of daily living that require loading on a flexed knee. Such activities include descending stairs, squatting, and sitting for prolonged periods of time.

PFPS is thought to result from abnormal patella tracking that causes excessive compression to the lateral patella facets. Possible reasons for faulty tracking have included quadriceps weakness, delayed activation (onset) of the vastus medialis (VM) relative to the vastus lateralis (VL), and decreased quadriceps electromyographic (EMG) amplitudes. However, conflicting results exist in the scientific literature. Some investigators have not found quadriceps onset timing differences while others have reported higher quadriceps EMG activity in subjects with PFPS. A possible reason for discrepancies might be the examination of these parameters during a variety of non-weight bearing and weight bearing activities.

Faulty hip kinematics also may contribute to PFPS. Powers et al were the first to compare femoral and patellar movement during non-weight bearing and weight bearing knee extension using kinematic magnetic resonance imaging. They reported lateral patella movement on the femur during non-weight bearing exercise but increased femoral internal rotation, under a relatively stable patella, during weight bearing activity. Results from this and a subsequent study have demonstrated that excessive femoral internal rotation, not patella movement, may cause relative lateral patella tracking. Findings from both studies have suggested that hip muscle weakness, especially of the hip abductors and external rotators, may lead to altered lower extremity kinematics.

Conflicting data have existed regarding an absolute association between hip weakness and altered lower extremity kinematics. Furthermore, Willson and Davis reported weak correlations between hip abduction strength/hip adduction excursion and hip external rotator strength/hip internal rotation excursion during single-leg jumping. Regardless of different findings, a recent systematic review found hip weakness in this patient population, and data support hip exercise as a viable treatment.

Researchers also have examined hip muscle EMG data during weight bearing activities. Souza and Powers found increased gluteus maximus EMG activation during demanding activities (e.g., running, drop landings, and a step-down maneuver) in females with PFPS who demonstrated hip weakness. They concluded that these subjects required increased gluteus maximus neural drive to complete these tasks. Cowan et al and Brindle et al reported a delayed onset of the GM relative to the vastii muscles at the beginning of a stepping task. Together, these findings have highlighted altered hip neuromuscular factors that deserve additional investigation.

While clinicians historically have prescribed quadriceps exercise for treating PFPS, an emerging body of evidence supports the inclusion of hip exercise. Additional information regarding the interrelationship between knee and hip muscle function may enhance exercise prescription for this patient population. Therefore, the purpose of this study was to compare hip and knee strength and EMG activity...
during stair descent in subjects with and without PFPS. We hypothesized that subjects with PFPS would demonstrate 1) significantly less hip abductor, hip external rotator, and knee extensor strength; 2) greater EMG amplitudes of the gluteus medius (GM), VM, and VL during stair descent; 3) delayed activation of the VM and VL at the onset of stair descent; and 4) a greater delay in GM activation compared to the VM and VL at the onset of stair descent when compared to subjects in the control group.

METHODS
This study represents part of a larger investigation that compared hip strength and hip and knee kinematics during stair descent in females with and without PFPS.17 Results from the larger study agreed with prior works that females with PFPS exhibit hip weakness. However, no between-group hip and knee kinematic differences existed during stair descent. The authors concluded that subjects with PFPS may have used a compensatory stepping strategy, similar to controls, because of hip weakness. Another reason may have resulted from differences in hip and knee neuromuscular activity, which is the focus of this portion of the overall study.

Subjects
Recent studies27,28 have suggested gender differences associated with strength and EMG activity. Therefore, only female subjects were included in this investigation. Based on the works by Boling et al7 and Ireland et al,29 a total of thirty-six subjects was deemed sufficient to determine differences with respect to EMG and strength variables. Eighteen females with PFPS (age = 24.5 ± 3.2 years, height = 1.7 ± 0.1 m, mass = 63.1 ± 9.1 kg, pain = 4.4 ± 1.5 cm, duration of symptoms = 14.4 ± 12.8 months) and 18 asymptomatic females (age = 23.9 ± 2.8 years, height = 1.7 ± 0.1 m, mass = 62.1 ± 8.5 kg) participated in this study. Females with PFPS participated in this study if they complained of: 1) anterior knee pain during stair descent and 2) pain during at least two of the following provocative activities: a) stair ascent, b) squatting, c) kneeling, or d) excessive sitting.13 They also rated usual knee pain over the previous week at a minimum of 3 on a 10-cm visual analog scale (VAS).30 The most affected lower extremity was tested for subjects with PFPS.9 Six subjects reported bilateral symptoms. Control subjects participated in the study if they had 1) no history or diagnosis of knee pathology; 2) no pain with any of the above-named provocative activities; and 3) no history of hip pathology. The right lower extremity was tested for control subjects.12 This was done to make as consistent as possible the process of data collection for these subjects as they were matched to each subject with PFPS with respect to age, height, and weight.

Subjects were excluded if they had 1) previous knee surgery or significant injury; 2) traumatic patellar dislocation; 3) any neurologic involvement that would affect gait; or 4) previous hip surgery or significant injury.9 Prior to participation, all subjects signed an informed consent approved by the University of Kentucky Institutional Review Board.

Instrumentation
Subjects’ pain was assessed using a 10-cm VAS. The extreme left side of the VAS stated “no pain” whereas the extreme right side stated “worse pain imaginable.” Subjects drew a perpendicular line on the scale at the position that most likely described their usual pain over the previous week.30

All isometric strength testing was performed using the Commander PowerTrack II™ (J Tech Medical, Salt Lake City, UT) hand-held dynamometer (HHD). The HHD’s calibration was confirmed prior to the study by placing known weights on the HHD and comparing this to the HHD’s reported weight. Accuracy was verified after every 10th testing session.

A 16-channel Myosystem 1400 EMG system (Noraxon USA, Inc, Scottsdale, AZ) was used to record muscle activity. EMG data were band pass filtered (10-1000 Hz) prior to sampling at 960 Hz. Video data were recorded using a seven camera video-based motion capture system (Motion Analysis Corporation, Santa Rosa, CA) operating at 60 Hz. EMG and video data were collected synchronously using EviRT 4.2 software (Motion Analysis Corporation, Santa Rosa, CA), and stored on a personal computer for later analysis.

Procedures
First, subjects completed a 10-cm VAS reflecting the typical pain level during the past week.30 Next, they rode a stationary bike for 3 minutes in a pain-free
range of motion at a submaximal speed. Subjects’ skin was prepared for EMG instrumentation by shaving, abrading, and cleansing with isopropyl alcohol prior to application of surface electrodes. Bi-polar Ag-AgCl surface electrodes (Medicotest, Rolling Meadows, IL), measuring 5 mm in diameter with an interelectrode distance of approximately 20 mm, were placed in parallel arrangement over the muscle bellies of the GM, VM, and VL in a standardized manner. Electrodes were further secured to the skin with an adhesive tape to prevent slippage during testing. A ground electrode was placed on the ipsilateral clavicle. Electrode placements were visually confirmed on an oscilloscope using manual muscle testing techniques. A 3-second standing “quiet” file was also recorded to exclude ambient noise.

Following EMG electrode placement, isometric strength measures were taken for the hip abductors, hip external rotators, and knee extensors (Figures 1-3). For the hip abductors, subjects were positioned in sidelying (unaffected leg directly on the table) with the test leg in a neutral position by placing pillows between the lower extremities. The HHD was placed over the lateral femoral condyle and secured with an immovable strap. For the hip external rotators, subjects sat with the hip and knees in 90º of flexion. The HHD was placed just proximal to the medial malleolus and secured with an immovable strap. For the knee extensors, subjects were positioned with the hip in 90º flexion and the knee in 60º flexion. The HHD was placed just proximal to the malleoli and secured with an immovable strap.

For testing, subjects produced a maximum voluntary isometric contraction (MVIC) using the “make” test to the beat of a metronome set at 60 beats per minute. They generated maximum force over a 2-second period and maintained this force for an additional 5 seconds to the beat of the metronome. Subjects performed one practice and 3 test trials, with a 30-second rest period between trials. A coefficient of variation was calculated.
and an additional trial was taken, if necessary, to ensure that subjects had 3 peak force measures with variability less than 10%. The order of muscle testing was counterbalanced to account for any potential bias. The peak value from each trial was recorded in newtons and converted to kilograms. EMG activity was simultaneously collected for the GM, VM, and VL during strength testing to determine a MVIC for each muscle and enable normalization of EMG data.

Next, retroreflective markers, with a diameter of 20 mm, were placed on subjects using a standard Cleveland Clinic marker setup. After obtaining a static neutral file, subjects were shown the stair stepping task and allowed 5 practice trials. They were instructed to ascend and descend two 20-cm high steps, ensuring that the test extremity lifted and lowered the body on the first and third steps, respectively. Subjects also took a minimum of 3 strides prior to and immediately following stair stepping in order to maintain a continuous movement pattern. Because movement velocity may influence EMG activity, subjects performed the task at a standardized rate of 96 beats per minute.

After demonstrating proficiency with the stair stepping task, subjects performed 10 test trials. Data from the last 5 trials were analyzed because of potential learning effects that might have been associated with earlier trials, even with subjects having performed 5 practice trials.

Seven subjects returned to the laboratory within 5 to 7 days in order to determine measurement reliability. For this purpose, they completed all procedures in the identical manner as on the initial testing day. Data from these subjects suggested that procedures used in this study had acceptable reliability (ICC > 0.70).

**Data Processing**

**Strength** We expressed all peak force values recorded on the HHD as a percentage of each subject's body mass. The average of the normalized force values from 3 trials having a coefficient of variation less than 10% was used for statistical analysis.

**EMG Activation Amplitudes** Raw EMG signals were further band pass filtered at 20 to 480 Hz using Datapac Software (Run Technologies, Mission Viejo, CA). To determine muscle activation amplitudes, EMG data from the last 5 trials were root mean square (RMS) smoothed using a 55-ms time constant. These data were then normalized to 100% of the stair descent cycle, ensemble averaged, and expressed as a % MVIC.

Since varying amounts of muscle activation can occur throughout stair descent, we identified three intervals for the stance phase of stair descent. Loading response began at the initial point where any part of the ipsilateral foot contacted the step and ended as subjects lifted the contralateral foot off the previous step (0% to 7% of the stair descent cycle). Single leg stance occurred when the test extremity supported the entire body mass during the stair descent (8% to 46% of the stair descent cycle). Preswing began when any part of the contralateral foot contacted the ground and ended as subjects lifted the test extremity's foot off the stair (47% to 58% of the stair descent cycle). The remaining 42% of stair descent represented the swing phase; however, data during this phase were excluded from analysis since the purpose of this study was to compare EMG activity during a weight bearing task. Based on these time percentages, Datapac software then calculated the average % MVIC EMG amplitude for each muscle during each interval. Values from the 3 intervals of stance were used for statistical analysis.

**Onset Timing Differences** Muscle activation onsets were determined at the beginning of stair descent using Datapac Software. For this purpose, data were band pass filtered as described above, full wave rectified, and low pass filtered at 50 Hz. A muscle onset was defined as the point in which the signal deviated by more than 3 standard deviations, for a minimum of 25 ms, over the baseline taken 200 ms before the trial began. All onsets were also visually confirmed since movement artifact could be incorrectly identified as the onset of muscle activity. After processing EMG signals and identifying muscle onsets, Datapac software calculated timing differences. GM onset was subtracted from the VM onset and VL onset, respectively, to quantify timing differences between the hip and knee musculature. A negative difference signified a delay in GM activation relative to the VM and VL where as a positive difference meant GM preactivation. VM onset also was subtracted from the VL onset to quantify quadriceps timing differences. A negative difference meant a delay in VM activation.
relative to the VL where as a positive difference signiﬁed VM preactivation. The average from the last 5 trials was used for statistical analysis.13

**STATISTICAL ANALYSIS**

Independent t-tests were used to determine group differences in age, height, and weight. Separate independent t-tests were used to determine differences in strength. Separate 2 by 3 (group X interval) analyses of variance (ANOVA) for repeated measures on stance interval were used to identify EMG amplitude differences for the GM, VM, and VL, respectively. A 2 by 3 (group X timing difference) ANOVA for repeated measures on muscle was used to determine EMG onset timing differences. An independent 1-group t-test was conducted to determine if timing differences varied signiﬁcantly from 0 (meaning simultaneous VM and VL activation) for the PFPS and control groups.13 All statistical analyses were performed using SPSS version 17.0 (SPSS, Inc., Chicago, IL). Level of signiﬁcance was established at the .05 level; the sequentially rejective Bonferroni (Bonferroni-Holm) post hoc test38 was used adjust the P-level to account for multiple pairwise comparisons of strength measures. The Bonferroni-Holm test also was used to determine the signiﬁcance of interactions for the two-factor ANOVAs.

**RESULTS**

Independent t-tests for subject demographics revealed similar age, height, and weight (P > .44) characteristics for both groups. Subjects with PFPS generated 22% less hip abductor (P = .007) and 21% less hip external rotator (P = .001) force output on the HHD than controls. Although not signiﬁcantly different (P = .148), subjects with PFPS exerted 13% less knee extensor force output than controls. Figure 4 displays these data.

A group by interval interaction effect showed that subjects with PFPS generated greater GM and VM EMG amplitudes than controls. During loading response, subjects with PFPS generated 2.1 times more GM activity (P = .001) and 1.3 times more VM activity (P = .003) than controls. They also generated 2.4 and 1.2 times more activity during single leg stance for the GM (P = .002) and VM (P = .020), respectively. All subjects demonstrated similar GM (P = .602) and VM (P = .413) activity during preswing as well as similar VL activity (P ≥ .07) throughout all intervals of stance. Figures 5 through 7 summarize these data.

No differences were identified with respect to EMG timing parameters (P > .07). Results from independent 1-group t-test to determine if VL - VM onsets differed signiﬁcantly from 0 were not signiﬁcant (meaning both groups had simultaneous VM and VL activation). Table 1 summarizes descriptive data for the EMG onset timing differences.
DISCUSSION

This study compared hip and knee strength along with EMG activity during stair descent in females with and without PFPS. As originally hypothesized, subjects with PFPS demonstrated hip weakness compared to controls. They also generated greater GM and VM EMG activity during the loading response and single leg stance intervals of stair descent. No other between-group differences existed for the remaining dependent measures.

Together, these results suggested that females with PFPS have altered strength and neuromuscular activity of the hip and knee muscles during a simple functional activity like stair descent. These findings further support the importance of hip exercise as...
part of a comprehensive rehabilitation program for this patient population.26

**Strength**

**Hip Abductors and External Rotators** Recently, many different groups of researchers21 have examined hip strength in females with PFPS and have consistently reported hip weakness. Moreover, many have assessed hip abductor18,28,39 and hip external rotator29,39-41 strength using similar subject position, HHD placement, and data normalization procedures as the current study. These similarities have enabled the ability to make meaningful comparison of our results to prior works.

Findings17,20,37 from prior investigations that used similar procedures reported hip abductor force values ranging from 21% to 29% body mass. Our results are in agreement as females with PFPS generated hip abductor force output equal to 22% of body mass. It is noteworthy that researchers40-43 that assessed hip abductor force values by placing the HHD proximal to the lateral malleolus reported relatively lower force values (range 9% to 18% body mass). Placing the HHD near the lateral malleolus provided the examiner a mechanical advantage (i.e., increased the externally applied moment arm) and would reduce the amount of force the subjects could place on the HHD.

Subjects in the current study generated hip external rotator force equal to 11% body mass, which also agrees with prior works18,29,39-41 that determined force output in a similar manner (range 9% to 17% body mass). These values were less than findings from Piva et al,42 who found that subjects with PFPS generated hip external rotator force output equal to 22% body mass. One reason for this difference may be the manner of testing since they placed the HHD proximal to the lateral malleolus with subjects positioned prone with the hip extended and the knee flexed to 90°.

**Knee Extensors** Our results did not agree with previous works showing quadriceps weakness in this patient population.5,44-47 A reason for this finding may result from our subject sample. Subjects in the current study presented with a long-term history of PFPS and might not have experienced pain during strength testing. Since we did not assess pain during strength testing, we cannot conclusively make this determination. From a clinical standpoint, our subjects with PFPS did demonstrate a 13% strength deficit compared to controls. These findings may be clinically relevant because patients with PFPS have responded favorably to quadriceps strengthening programs.5,5

In summary, subjects with PFPS demonstrated significant hip abductor and external rotator weakness. Values from the current and prior works may serve as a benchmark that clinicians can use to identify females with PFPS who have hip weakness. However, knowledge of the assessment methods used are critical to ensure reliable use of the reported values.

**EMG Activation Amplitudes**

**GM and VM Activity** Subjects with PFPS demonstrated significantly higher GM and VM EMG amplitudes during the loading response and single leg stance intervals of stair descent. Relatively higher GM activation may have reflected the need for increased neuromuscular activity to complete the task. Conversely, Souza and Powers19 found that females with PFPS had less hip abductor strength but similar GM activity as controls during a running, drop jump, and a step-down maneuver. They concluded that subjects could have compensated for hip abductor weakness through excessive trunk lean over the ipsilateral hip during these tasks. Excessive trunk lean would minimize the amount of required muscle force needed to stabilize the pelvis.48

Subjects in the current study completed a stair descent task, which was less demanding than tasks used by Souza and Powers. Therefore, subjects in the current study may have relied more on greater GM activity, and not a trunk lean strategy, to complete the task. The authors cannot conclusively make this determination as trunk kinematics were not assessed.

Regarding the VM activity, Sheehy et al10 identified two peaks of eccentric EMG activity for the VM and VL during stair descent. The first corresponded with the current study’s loading response and single leg stance intervals. During these intervals, researchers have reported greater hip muscle activation in response to decelerating and controlling forward and downward motion of the body onto the step.49,50 Higher VM amplitudes for PFPS subjects during these intervals also most likely reflected the need for greater activation when external knee flexion moments were greater.51 Sheehy et al also identified a second peak of activity, which corresponded to preswing in the
current study (movement of the center of mass past the stance leg). During this interval, the body was likely positioned with the center of mass located more centrally over the foot, which would provide a stable base and require less muscle activation.49

**VL Activity**

Subjects with PFPS demonstrated similar VL amplitudes as controls throughout all intervals of stair descent, findings that agree with prior works.8,30,52 Compared to the VL, these subjects also generated greater VM activity. This difference may suggest relative VM insufficiency. Souza and Gross53 also reported relative differences in VM and VL activity for subjects with PFPS during stair-stepping. However, they reported decreased VM activity relative to the VL. It is unclear why Souza and Gross found less VM activity compared to the VL. It is noteworthy that they did not normalize the EMG data and had a smaller sample size. These methodological differences might account for the conflicting findings.8

**EMG Onset Timing Differences**

**VM and VL Onset Timing Differences**

Results from this study showed simultaneous activation of the VM and VL at the onset of stair descent, which agree with previous reports.8,10 However, findings from this study contradicted those reported by Cowan and colleagues8,25 and Boling et al.7 Conflicting results most likely reflected differences in methodology and subject variability. Future studies that use a standardized methodology and similar subject profile are needed to better understand the clinical importance, if any, of VM and VL onset timing differences.

**GM and Vastii Muscle Onset Timing Differences**

All subjects in the current study demonstrated delayed GM activation relative to the VM and VL; however, there were no significant between-group differences. Although Brindle et al.9 also reported a similar delay in GM activation, subjects with PFPS exhibited a significantly greater delay in GM activation than controls. Subjects in the Brindle et al study ascended 3 steps, stopped, turned around, and descended the steps. Subjects in the current study ascended and descended steps in a continuous manner. Variations in methodology compromised meaningful comparisons between studies; additional studies are needed to better understand timing characteristics between the GM, VM, and VL.

**Clinical Implications**

Findings from this study have provided additional insight regarding the interaction between hip and knee strength and EMG activity in females during stair descent. The authors’ current data support that clinicians examine and address hip impairments for the treatment of PFPS. However, they also should not disregard knee function as patients who may not necessarily demonstrate marked knee weakness may have altered neuromuscular activity. It is noteworthy that programs designed to target the hip muscles7,22,24,54 also incorporated some weight bearing exercises that simultaneously engaged the hip and knee. Although patients in these investigations reported less pain and exhibited increased strength, it is unknown if changes occurred in neuromuscular recruitment. Directing more attention toward the effect that exercise has on hip and knee neuromuscular factors may provide invaluable information regarding future exercise prescription.

**Limitations**

This study had certain limitations that the authors would like to address. The first limitation was associated with the use of surface EMG with respect to signal crosstalk. Other muscles like the tensor fascia lata and gluteus minimus might have influenced EMG signals. We addressed this limitation by placing electrodes over the muscle belly of the gluteus medius in a standardized manner31,55 and confirmed EMG signals using manual muscle testing techniques. Future studies could address this issue by utilizing fine wire EMG techniques. A second limitation was that the primary examiner was not blinded to each subject’s condition. Bias might have been introduced unintentionally during data collection and analysis. The authors did minimize potential bias by taking measures in accordance with a standardized protocol with proven reliability.17,36

**Delimitations**

First, the authors did not assess gluteus maximus function since prior studies specifically focused on the hip abductors and hip external rotators. However, more recent investigations18,39,40 have examined the gluteus maximus. Although considered the primary hip extensor, the gluteus maximus also functions as a strong hip external rotator. Emerging data19 have shown that subjects with PFPS exhibit gluteus maximus weakness.
and increased EMG activity during a running, drop jump, and step-down maneuver. Additional investigations are needed to better understand the influence of the gluteus maximus on patients with PFPS.

Second, the authors of the current study did not instrument any of the hip external rotators with EMG electrodes. These muscles would have required the use of fine wire techniques to record EMG activity, which presented concerns of possible wire breakage during testing. Furthermore, unlike the gluteus medius, the primary hip abductor, no single muscle within the hip external rotators would best represent the actions of this muscle group.

Finally, the muscles examined in this study produce rotatory joint movement, which should be measured as a unit of torque (force generated multiplied by the perpendicular distance of the applied resistance from the joint axis of rotation). We quantified strength as the amount of force applied to the HHD expressed as a % body mass to enable comparison of results to prior studies. Future studies should report data as a unit of torque to provide a more accurate reflection of strength.

CONCLUSION
The purpose of this study was to determine differences in hip and knee strength and EMG activity during stair descent in females with and without PFPS. Overall, subjects with PFPS exhibited hip weakness. Caution should be taken in interpreting this finding, since it is not known if hip weakness was the cause of or a result of PFPS. EMG data showed that subjects with PFPS generated greater GM and VM activity during the loading response and single leg stance intervals of stair descent. Overall, the findings of the current study concur with the emerging body of evidence regarding hip abductor and hip external rotator weakness in this patient population and support the need for further examination of neuromuscular factors.

REFERENCES


40. Robinson RL, Nee RJ. Analysis of hip strength in females seeking physical therapy treatment for...


ABSTRACT

Purpose/Background: Ultrasonography (US) may aid the assessment of the anterior talofibular ligament (ATFL) injury after lateral ankle sprains by allowing the clinician to visualize and measure talocrural laxity. Comparison of US against another objective method of ankle laxity assessment, such as ankle arthrometry (AA), is needed. The purpose was to evaluate the relationship between the ATFL length measurements measured from stress US images to the inversion and anterior drawer displacement measured with AA in healthy subjects.

Methods: This descriptive laboratory study included 26 ankles from healthy subjects. The apparent length of the ATFL was measured using US during anterior drawer (USAD) and inversion (USINV) stress and the translation of the talocrural joint was measured using AA during anterior drawer (AAAD) and inversion (AAINV) stress. Percent change in length for USAD and USINV were quantified. Intraclass correlation coefficients and pearson product moment correlations Bland-Altman limits of agreement were calculated between relevant variables.

Results: USAD and USINV percent change in length were positively correlated (r = .76). Bland Altman analysis revealed a mean difference of 5.38 mm (95% CI: –3.5 to 12 mm) with the AAAD producing higher values than the USAD. No significant correlations were found between the US and AA variables, however the absolute AAAD and AAINV variables were also positively correlated (r = .61).

Conclusions: The US and AA variables were not directly correlated when measuring inversion and anterior laxity in healthy ankles. Differences between the devices that may affect this include different rates of joint loading, patient position and method of assessing laxity. The AA results demonstrated greater anterior displacement. Results may differ in ankle injured subjects who may demonstrate increases in anteroposterior and inversion laxity.

Level of Evidence: 2b. Exploratory study in healthy cohort.

Key Words: ankle laxity, anterior displacement, inversion rotation, percent length change
INTRODUCTION
Lateral ankle sprains are common injuries and inadequate diagnosis and treatment can have long-term negative effects including instability, pain, and dysfunction. These injuries make up approximately 25% of the injuries from running and jumping sports. The lateral ankle is supported primarily by the anterior talofibular ligament (ATFL) and the calcaneofibular ligament (CFL), and injury to one or both of these ligaments may lead to increased anterior drawer and inversion laxity. Current assessment techniques of the ATFL include manual physical examination, radiography including stress radiographs, magnetic resonance imaging (MRI), arthograms, and arthrometry. Each of these has limitations in clinical practice such as questionable reliability, radiation exposure, or device availability. The use of stress ultrasound (US) in the evaluation of the ATFL may provide diagnostic information regarding the extent of the ligament injury and talocrural joint integrity. Stress ultrasound, or ultrasonography, is used to describe imaging of the ankle joint during anterior drawer or inversion stress to identify changes in talofibular position resulting from the stress. It is similar to stress radiography in that the same joint stress is applied; however, ultrasound is used to image ankle anatomy rather than radiography.

Ankle arthrometry (AA) is an objective measure of rearfoot inversion and anterior ankle displacement and is a reliable and valid measure of talocrural and subtalar joint stability. The Hollis ankle arthrometer (Blue Bay Research, Milton, FL) is a device specifically designed to measure ankle joint laxity and Kovaleski et al demonstrated high interrater and intrarater reliability. Kovaleski et al. found a strong correlation between arthrometer variables of anterior to posterior translation (r = .88) and inversion (INV) (r = .86) when compared to the actual motion occurring between the tibia and calcaneus as demonstrated by pins inserted into the bones of cadaver ankles. Ankle arthrometry has been used to assess anterior and inversion laxity in patients with acute ankle sprains and chronic ankle instability. Currently, AA is primarily limited to research applications since the device is not widely available in clinical practice settings.

Ultrasound can be used to visualize the ATFL from the malleolar origin to the talar insertion and the apparent ligament length can be measured using a digital caliper either during the exam or later using the saved images. A longitudinal measurement between the bony attachments of the ATFL is taken by identifying the fibular origin and performing a straight-line measurement along the ATFL fibers to the insertion on the talar neck. When using this method, Brasseur et al. reported high accuracy using a longitudinal US ATFL imaging compared to arthroscopy in the identification of morphological changes suggestive of ATFL injury in 34 patients (19 males, 15 females) in need of ankle arthroscopy (mean age 29 years, range 13-55) presenting clinically with both acute and chronic lateral ankle injuries. Campbell et al. included manual anterior drawer stress to an US exam and further identified ATFL injury indicating that the combined use of US imaging and ankle joint stress, followed by measurement of the changes in talofibular displacement using methods described by Brasseur et al and Glaser et al. may provide clinicians with more accurate and reliable information on talocrural joint integrity than do the manual anterior drawer and talar tilt stress tests.

Although US imaging of the ATFL can provide valuable information regarding the structure and the distance between bony attachments, it is unknown
whether changes in the length of the ATFL represented on an US image are related to the talocrural displacement measured with an ankle arthrometer. The authors hypothesize that the amount of ATFL lengthening measured from an US image during anterior drawer and inversion are directly related to the amount of anterior translation and inversion degrees of laxity measured with an ankle arthrometer during separate trials. The purpose of this study was to evaluate the relationship between the ATFL length measurements measured from stress US images to the inversion and anterior translation observed with AA in healthy subjects.

**METHODS**
This descriptive laboratory study explored the relationship between absolute length measurements of the ATFL during anterior drawer and inversion stress and depicted on an US image (USAD and USINV, respectively), the relative changes in ATFL length during the anterior drawer and inversion stress, using ultrasound analysis (USAD% and USINV%, respectively) with the anterior drawer and inversion laxity results obtained using the ankle arthrometer (AAAD and AAINV, respectively). The relationships of particular interest were those between the following variables: USAD and AAAD, USAD% and AAAD, USINV and AAINV, and USINV% and AAINV. Secondary relationships of interest were between USAD and USINV, USAD% and USINV%, and finally between AAAD and AAINV.

**Subjects**
Twenty-six healthy subjects (12 males, 14 females) who had no history of injury to at least one of their ankles participated. Fifteen subjects had no history of injury to either ankle, while 11 subjects had a history of unilateral ankle injury. For the purposes of this study, a randomly selected ankle from the participants with no injury history was chosen and the uninjured ankle was used in subjects with a unilateral history of injury for 26 ankles included. See Table 1 for subject demographic information.

Exclusion criteria included a history of bilateral ankle sprains, ankle or tarsal fracture, or current skin lesions around the foot or ankle region. A Latin square was used to randomize the order in which the AA or the US assessments were performed. All subjects were informed of the possible risks associated with the experiment and signed a consent form prior to participation. The university institutional review board approved the study methods.

**Instruments**
A portable US unit with a 38 mm linear transducer probe operating at 8 MHz (GE Logic Book PRO, Fairfield, CT) was used to acquire US images in conjunction with the LigMaster™ multi-joint arthrometer (SportTech, Inc. Charlottesville, VA) that was used to apply 125 N of anterior drawer force and to invert and stabilize the ankle near the end range of inversion range of motion. The Hollis ankle arthrometer (Blue Bay Research Inc., Milton, FL) was used to apply and measure the amount of anterior ankle translation during 125 N of anterior drawer force and degrees of ankle inversion motion with a 4000 N*mm of inversion torque.

**Testing procedures**
A flow chart of subjects through the study is shown in Figure 1.

| Table 1. Subject demographics (n=26). Values are represented as means ± SD. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Age (years)     | Height (cm)     | Mass (kg)       | BLS             | Foot Length (cm) |
| 24.8 ± 4.6      | 172.9 ± 9.3     | 74.7 ± 18.1     | 2.7 ± 2.2       | 24.6 ± 2.3      |

BLS= Beighton Laxity Score; cm= centimeter; kg= kilogram.
Ultrasound Exam
US images were taken in three positions (neutral, inversion, anterior drawer). Anterior drawer and inversion testing positions are shown in Figures 2 and 3. Standard ultrasound transmission gel was used as the conducting agent. Neutral images (USNEUT) were captured first while the subject was sidelying with the ankle joint in a neutral position (0° dorsi/plantar flexion and 0° inversion/eversion). While in this position, three images of the ATFL were obtained after identifying the bony landmarks of the talus and lateral malleolus.15 Between each USNEUT image, the examiner removed the US probe and the subject actively moved the ankle 3 times into full plantar and dorsi flexion and then returned to the neutral position for the subsequent images.

USINV images were taken with the subject in the supine position with the heel resting in the heel cup of the LigMaster™. The heel cup was then fastened securely to the ankle as it rested in approximately 30° of plantar flexion. The cushioned pressure actuator placed 3.0 cm proximal to the medial malleolus applied lateral displacement of the leg causing the ankle to rotate passively to end range of motion. The subject was instructed to relax the muscles of the leg while the ankle was passively inverted to the end range of ankle inversion and the degrees of motion were recorded using the digital output from the LigMaster™ device that uses a rotary encoder device within the frame to detect angular displacement with ankle inversion. Once positioned, the US probe was used to acquire an image. The inversion stress was then released following each image and then reapplied to the same end-range position previously determined at the first.

Next, three images were obtained of the ATFL while an anterior drawer stress was applied to the ankle. The subject rested in the sidelying position with a slightly flexed knee and the medial heel resting against the LigMaster™ device. The examiner applied a 125N force with the pressure actuator to the distal tibia resulting in posterior tibial displacement over a fixed foot and ankle joint. The ATFL was then identified with US and an image was taken. The stress was then released, and reapplied until three images were taken and stored for later measurement. US images were stored in digital format for subsequent analysis using ImageJ v. 1.42k software (ImageJ, U. S. National Institutes of Health, Bethesda, MD).

The origin and insertion points of the ATFL were used as bony landmarks during the acquisition of the US images to ensure standardization of the ATFL across different images in a manner similar to previously reported methods.14,5 The anterolateral aspect of the
lateral malleolus was identified as the ATFL origin and
the peak of the talus was used as the insertion point.
The peak of the talus also represents the anterior
aspect of the lateral talar articular cartilage and the
lateral neck of the talus. These bony landmarks can be
identified by their hyperechogenic nature and were
verified during ankle movement to ensure that the
talar insertion was consistently selected at a similar
location across images.16 Figure 4 depicts an example
of the US images used in this study.

In the measurement of the US images, three examin-
ers independently identified and selected the lateral
malleolus origin and talar insertion of the ATFL. A
straight-line caliper was used to measure the linear
distance (mm) between the landmarks. The US image
had a field of view of 13.3 by 10.8 cm in size and 521
by 412 pixels in resolution. To standardize the linear
measurement for all images, the digital caliper was
calibrated to 13.8 pixels per mm from a scale that
appears on each image. The examiners trained in this
US technique were blinded to ankle position (neutral,
anterior drawer, and inversion) during the measure-
ment process. Each examiner measured each image
once, the mean of each of the individual examiner's
means were found, and a grand mean was taken from
these three means and was used in the final analysis.
Normalized length change values are similar to those
used by Ozeki et al17 and were calculated from the
USNEUT values for both USAD (USAD%) and USINV
(USINV%) using these formulae:

\[
USAD\% = \left( \frac{USAD - USNEUT}{USNEUT} \right) \times 100
\]

\[
USINV\% = \left( \frac{USINV - USNEUT}{USNEUT} \right) \times 100
\]

Stress ultrasound measurement reliability was
assessed by a pilot study that involved measuring
the captured images from 20 ankles taken during
the three test conditions (180 images). The examin-
ers were two post-professional athletic training mas-
ters students with additional training in US to both
acquire the images and perform the ATFL measure-
ments with ImageJ software. Each examiner inde-
dependently measured each image once and a mean
ATFL length was calculated for each ankle, at each
position. The interexaminer reliability of these posi-
tion means was calculated from these means.

Intraexaminer reliability was measured by a third
examiner who measured the same data set on two dif-
ferent days and the mean ATFL lengths of each ankle,
at each position were used to determine the test-retest
reliability. The examiner was a physical therapist
with 13 years of clinical experience and 5 years of
experience with using US. Intraclass correlation coef-
ficients were calculated on the average measures.
Intraclass correlation coefficients (ICC_{3,1}) were 0.77
(95% CI: .42, .91) for neutral; 0.91 for anterior drawer
(95% CI: .78, .97) and 0.91 for inversion (95% CI: .71,
.96) for interexaminer reliability. Intraexaminer reli-
ability was 0.93 for neutral (95% CI: .81, .97), 0.94 for
anterior drawer (95% CI: .71, .98) and 0.96 for inver-
sion (95% CI: .89, .98).

**Ankle Arthrometer**

AA variables were obtained as previously described
by Hubbard et al.11,12 The subject was placed in the
AA with the heel secured in a specialized cup and a
clamp secured over the talus (Figure 5). A pad was
placed against the anterior tibia and secured around
the leg. The subject was then moved to a supine
position with the foot and AA off the edge of the
plinth. A stabilization belt was placed over the shank
to restrict movement during the exam. Three trials
of anterior drawer were performed to 125 N of force
and peak anterior displacement (mm) was recorded.
The ankle was then inverted three times with 4000
N*mm of torque and the peak amount of inversion
displacement was measured in degrees. The mean value of the three trials for each position was used for statistical analysis. These procedures with this device have previously demonstrated inter- and intratester reliability of .80 to .97.4

Statistical analysis
The US dependent variables were USAD mean length, USINV mean length, USAD%, and USINV%. The instrumented arthrometer dependent variables were AAAD (mm) and AAINV (°). A bivariate correlation analysis was used to determine the relationships between the 6 dependent variables. The alpha level was set a priori at p<.05 for all correlation analyses. A Bland-Altman plot was used to determine the limits of agreement between the USAD and AAAD variables.18

RESULTS
Descriptive statistics are shown in Table 2 and correlation analysis results are shown in Table 3. No significant correlations were identified within the primary relationships of interest between AA and US variables. The secondary comparisons of interest between USAD - USINV and USAD% - USINV% were both strongly correlated, as was the AAAD and AAINV comparison. Figure 6 shows the Bland-Altman plot and reveals the mean difference between the USAD mean displacement and the AAAD mean length measurement. The AAAD variables were, on average, 5.38 mm (95% CI: -3.5 to 12 mm) greater than the USAD variables; a nonsignificant finding due to the width of the confidence interval.

DISCUSSION
There were no significant correlations between the US and AA variables used during the assessment of anterior drawer or inversion laxity in the four key comparisons of interest. Strong, positive correlations were observed on the three secondary comparisons of interest between USAD and USINV and the AAAD and AAINV variables, respectively; a finding that suggests both the US and AA method are revealing similar patterns of anterior and inversion ankle laxity through two considerably different techniques. The measurement of AAAD tended to be 5.38 mm greater than USAD indicating that each method is quantifying anterior talocrural laxity differently and that the sources of both laxity and error must be considered when evaluating and using both the US and AA method.

Table 2. Descriptive statistics for all subjects. Represented as mean ± Standard Deviation

<table>
<thead>
<tr>
<th></th>
<th>USNEUT</th>
<th>USAD</th>
<th>USINV</th>
<th>AAAD</th>
<th>AAINV</th>
<th>USAD</th>
<th>USINV</th>
</tr>
</thead>
<tbody>
<tr>
<td>(mm)</td>
<td>(mm)</td>
<td>(mm)</td>
<td>(°)</td>
<td>(mm)</td>
<td>(%)</td>
<td>(mm)</td>
<td>(%)</td>
</tr>
<tr>
<td>18.7 ± 0.2</td>
<td>19.0 ± 0.2</td>
<td>20.1 ± 0.2</td>
<td>5.6 ± 2.8</td>
<td>25.7 ± 9.1</td>
<td>1.7 ± 10.5</td>
<td>7.6 ± 9.9</td>
<td></td>
</tr>
</tbody>
</table>

AAAD= ankle arthrometer anterior drawer translation; AAINV= ankle arthrometer inversion rotation; USAD= ultrasound length during anterior drawer stress; USAD%= normalized mean ATFL length change with anterior drawer stress; USNEUT= ultrasound length in neutral ankle position; USINV= ultrasound length during ankle inversion; USINV%= normalized mean length change with inversion stress.
The lack of correlation between the US and AA variables may be attributed to the small changes in ligament lengthening in subjects without a history of ankle injury. For example, the mean USAD% was less than 2% in this study. This small amount of excursion may have limited the utility of the Pearson’s correlation to detect a relationship between the two variables in this sample. Jeys et al. indicated that normal ankle ligament changes with motion are less than 5%. If the normal ligament is lengthening only a small amount from its resting length in a neutral position, then a linear correlation may not exist, particularly when evaluated at a single absolute load of 125 N. The relationship may differ in ankles with ATFL injuries that exhibit increased lengthening due to injury. The subjects in the current study were healthy individuals with no history of ankle injury. Healthy subjects were used since this study was the first to explore a relationship between these devices and the authors did not want any displacement or laxity measurements to be affected by pain during testing. It was hypothesized that as the USAD displacement value increased, the AAAD length measurement would increase, but the results did not support that hypothesis. Analyzing this relationship with a Bland-Altman plot, the AAAD consistently produced 5 mm more translation in comparison to USAD. The current US measurements of mean ATFL lengths were similar to those described in both anatomical and MRI studies. Also consistent with current findings reported in Table 2, were the findings of de Asla et al. who reported in-vivo ATFL length changes in healthy ankles from 16 mm in neutral to 20.8 mm during active ankle plantar flexion and supination motion using MRI. ATFL length was found in the de Asla et al. study by measuring the linear distance between the centroids of both the lateral malleolus and talus at different positions of ankle active motion using 4 healthy ankles. Significant changes in length of the ATFL were observed with the supinated position, which was similar to the inversion position used in this study.

The AA and the US methods used in this study have four key differences that may explain the inability to identify relationships between the ankle laxity variables. First, The AA uses digital sensors that are placed away from the talocrural joint on a footplate and a tibia pad. This arrangement allows for subtalar motion, soft tissue compressibility and leg motion to be captured resulting in additional movement and systematic error that is not captured with an US image. Second, the US uses a two-dimensional image of the ligament from origin to insertion. While the stress applied to the ankle during US imaging is similar to that used during the AA method, the US image (and relative changes between positions) isolates changes to predominantly talofibular motion. US measurements taken between the talus and fibula do not account for subtalar motion that the AA device measurement includes, both in anterior displacement and inversion. Third, the subject is supine.
with the knee in 0° of flexion and 0° of plantarflexion during the AAAD test and in sidelying with the knee slightly flexed to approximately 30° during the USAD condition. The extended knee position may increase the passive muscle tension from the gastrosoleus complex and thereby alter ankle laxity and stiffness.\textsuperscript{21} Finally, the rate and duration of joint loading used was different between the two stress devices. The magnitude of loading was similar (125 N) for both devices, but the AAAD requires the examiner to load the ankle joint at a rate of approximately 30 N/sec while, during the USAD exam, the rate of joint loading is only 10-12 N/sec using the LigMaster™ device. The ankle then remains at a constant load of 125 N until the examiner can capture an ATFL image, a process that may take 15-30 seconds, possibly allowing tissue creep to occur. These same issues are present during the inversion testing which may similarly account for differences between these variables. The contributions of these factors help explain the differences between these variables of ankle laxity.

When comparing the AAAD with the AAINV variable a strong, positive correlation was found. This correlation indicates that as the displacement increases in the AAAD, that a corresponding increase in the degrees of AAINV rotation occurs in healthy ankles. This may occur to a greater degree in subjects with greater physiological laxity. Kovaleski et al also tested AAAD and AAINV both before and after sectioning of the ATFL and CFL in cadaver ankles and observed changes in inversion rotation after sectioning of the ATFL, suggesting that increases in anterior displacement are accompanied by concomitant increases in inversion rotation.\textsuperscript{4} Hubbard et al found that AAAD and AAINV were both effective at measuring ankle laxity and indicated that similar changes in both inversion degrees of motion and anterior displacement existed between healthy and ankle-injured subjects, even in subjects suspected of having only ATFL injuries without CFL involvement.\textsuperscript{10} Similarly, these results found a strong positive correlation when analyzing the USAD and USINV variables. This is an interesting finding in context of the AAAD and AAINV relationship and suggests that while the AA appears to measure the laxity of the entire ankle complex (talocrural and subtalar joints) the US methods focus upon ATFL changes and talofibular motion alone. A strong positive correlation was also revealed when comparing the USAD% normalized length with the USINV% normalized length and suggests that the normalized ATFL length changes visualized with US reflect similar relationships between each other as do previously validated methods of mechanical arthrometry.

Previous authors have reported AA results in healthy subjects and those with ankle instability in terms of total anteroposterior and inversion-eversion displacement.\textsuperscript{9,22} The present study measured the only mean maximum anterior displacement and mean inversion rotation and observed 5.64 ± 2.79 mm of anterior translation in healthy ankles and a mean inversion rotation of 25.6 ± 9.0°. Hubbard et al\textsuperscript{22} reported total anteroposterior translation of 18 ± 4 mm and inversion rotation of 32 ± 3°.\textsuperscript{22} The combination of anteroposterior or inversion-eversion displacements were not used because the authors' interest was not with anteroposterior laxity, but merely the direction-specific laxity in the anterior and inversion motions in order to make comparisons to the US variables.

This authors of the current study evaluated the mean anterior displacement using AA against the mean anterior displacement as measured between two bony landmarks rendered on an US image. While theoretically related, each procedure has sources of error that occur which may be of different magnitude. Such uncontrollable sources of error are limitations of this study. Also, a limitation noted is that healthy subjects were included who do not have a history of capsulo-ligamentous ankle injuries and the "normal" laxity present may be small thus limiting the applicability of the Pearson product moment correlation as a method to characterize any hypothesized relationships. Further investigations that attempt to characterize the relationship between these two methods for quantifying ankle laxity should consider methods that use a range of applied loads and degrees of motion.

**Conclusion**

Variables of ankle laxity from the US and AA images were not directly correlated when measuring inversion and anterior laxity in healthy ankles. The lack of correlation between the USAD and AAAD variables may stem from unique aspects of each measurement device such as differences in subject positioning, sources of measurement error, and the rate of ankle...
joint loading. Additionally, the AA quantifies total ankle joint complex displacement while the US method specifically isolates changes to the talofibular aspect of the talocrural joint. Thus in healthy ankles, it appears that the US method and AA are not measuring the same components of ankle joint laxity. Future studies should examine the use of these two assessment techniques in ATFL-injured subjects to examine the relationship between measured variables.

REFERENCES


ABSTRACT

Background: The lack of proper scapular kinematics can limit the function of the entire shoulder complex. Many forms of scapular dyskinesis have been proposed along with tests to measure for the position and motion associated with those positional and movement faults. While scapular internal rotation has been listed among the forms of scapular dyskinesis there has not been a reliable test documented in the literature that examines this motion. The purpose of this study was to determine whether an innovative scapular medial border posterior displacement measurement device has adequate inter-rater and intra-rater reliability when used at rest and during the sitting hand press up test.

Methods: 16 male Division III baseball players free of upper limb injury for the previous 12 months participated in the study. Posterior scapular displacement measures were taken on each subject in a resting static posture and while performing a sitting hand press up test. Subjects were tested twice within 24 hours by two separate examiners. Intraclass correlation coefficients (ICC) were calculated to determine intra-rater and inter-rater reliability.

Results: The intra-rater reliability for rater 1 was .97 (95% confidence interval [CI] = .91-.98), for the rest position and .95 (95% CI = .86-.98) for the sitting hand press-up position. Intra-rater reliability for rater 2 was .99 (95% CI = .97-.99) for the rest position and .98 (95% CI = .95-.99) for the sitting hand press-up position. The ICCs for inter-rater reliability of the scapular medial border posterior displacement measurement device in at the rest position and the sitting hand press-up position were .89 (95% CI = .81-.96) and .89 (95% CI = .80-.96) respectively.

Conclusions: The findings of this study indicate that the measurement of medial border posterior displacement using this device demonstrates good to excellent inter-rater and intra-rater reliability.

Key Words: reliability, scapular dyskinesis, sitting hand press up test

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INTRODUCTION
Proper alignment and motion of scapula are important to the function of the glenohumeral joint for two reasons. First, the position of scapula on the thorax aligns the glenoid with the humerus to allow for smooth movement in multiple planes of motion. Second, the scapula is the origin of the rotator cuff muscles, which provide dynamic stability to the joint by compressing the head of the humerus into the glenoid. Without proper alignment the rotator cuff muscles would be at a disadvantage due to changes in their length-tension ratio as well as their angles of pull.1,5 Movement of the scapula is complex. It is comprised of three rotations—upward/downward rotation which occurs around a horizontal axis perpendicular to the plane of scapula, internal/external rotation which occurs around a vertical axis in the plane of the scapula, and anterior/posterior tilt, which is a rotation around a horizontal axis in the plane of the scapula; two translations—elevation/depression, and superior/inferior glide; and finally, protraction/retraction, which has been described as a combination movement between and anterior/posterior glide and internal/external rotation.1,2,7,8 An example of this coordinated movement can be observed during humeral elevation when the scapula moves into upward rotation, which when combined with the 2 to 1 ratio of movement with the glenohumeral joint allows for full overhead motion. Concurrently, the scapula posteriorly tilts raising the acromion to prevent impingement, and externally rotates to allow the head of the humerus to rotate on the center of the glenoid as it progresses through the full range of motion.

In recent years, there has been a great deal of research that has focused on alterations in normal scapular positioning and movement. These alterations known as scapular dyskineses have been linked to many glenohumeral joint injuries such as impingement syndrome, labral damage, and rotator cuff tears in overhead athletes.1,2,7,9-12 These conditions can be caused by a loss of upward rotation, an increase in internal rotation, an increase in protraction, or an increase in anterior tilt which together or separately can affect the subacromial functional space leading to glenohumeral pathologies.1,10-12 These changes in scapular motion have been linked to muscular tightness, fatigue, and weakness of the scapular positioning muscles that include the rhomboids, serratus anterior, lower trapezius, middle trapezius, upper trapezius, and pectoralis minor.2,3,8,13 While a limitation in any one of the scapular movements can put the shoulder at risk for injury, Kibler et al.7 described three types of scapular dyskinesis that put shoulders at risk: Type I, which is characterized by an inferior medial border prominence, Type II that is characterized by a medial border prominence, and Type III characterized by a superior medial border prominence. All three of these dysfunctions highlight alterations in the rotational position of scapula. Warner et al.9 found that 54% of subacromial impingement patients had an increase in medial scapular border prominence.

Subjective scapular posture and movement analysis have been part of clinician’s shoulder evaluations for quite some time, however, recently, objective measures have been developed to assist in accurate diagnosis and with pre-injury screening. The lateral scapular slide test looks at the amount of protraction by measuring the distance from the midline to the medial border of scapula.10 Inclinometers have been used aligned with the spine of scapula to measure upward and downward rotation.4 There are also clinical tests that seek to eliminate symptoms by providing manual corrections to the scapular dysfunction such as the scapular reposition test, modified scapular assistance test, and the scapular retraction test.5,12 Some believe that these evaluations are limited by the lack of muscular activity during their performance, in contrast to the increased medial scapular prominence one might see when a subject does a push-up against a wall, or the change in rotator cuff strength during testing when the scapula is in different positions.3,5,6 There are also evaluations that require expensive equipment like an EMG unit that measures the timing of the scapular muscle activation, or 3-D motion capture analysis systems that evaluate the movement of the scapula, but are still not capable of capturing the motion of the scapula during highly dynamic activities like throwing.8,10,14 With the current measures that are available, the average clinician still lacks an affordable way to evaluate the one motion that may have a significant impact on shoulder injuries in the overhead athlete, medial border prominence or more accurately scapular internal rotation.

The device used in this study was designed to measure the distance from the rib cage to the medial border of the scapula while at rest, as well as when the scapular
stabilizing muscles are placed under a load. The isometric load was imparted through the use of sitting hand press up test which involves the subject pressing down into a table or chair from the seated position and raising their body weight up for 5 seconds while a measure of the scapular medial border posterior displacement is taken. The sitting hand press up test requires extension at the shoulder, extension of the elbow, as well as flexion at the hip and knee. This position requires extreme stabilization of the shoulder girdle, particularly the scapulo-thoracic joint. The purpose of the study is to establish whether this new tool can provide a reliable means of screening for scapular medial border posterior displacement at rest and during the sitting hand press up test. It is the authors’ hypothesis that the testing protocol, using the novel scapular measurement tool, will prove to be a reliable method for evaluation of scapular medial border posterior displacement.

METHODS
A total of 16 Division III male baseball players (19.5 ± 1.3 yrs, 184.9 ± 7.2 cm, 88.6 ± 10.4 kg) volunteered for the study. Exclusion was based on any history of shoulder pathology (dominant or non-dominant side), including injuries to any part of the shoulder complex, not just the glenohumeral joint. Subjects provided informed consent prior to participation, as approved by Willamette University's Institutional Review Board for the Protection of Human Subjects.

All measurements were taken with a standardized scapular medial border posterior displacement measurement tool (Figure 1) in two positions, a resting and a sitting hand press-up position. Prior to measurement, subjects were instructed: “relax and stand in your normal standing position.” At this point, the length of the medial border of each scapula was determined by measuring the length of a line drawn from the superior angle to the inferior angle. A mark was then placed at the midpoint of the line to use as a reference point for placement of the measuring tool during testing. The measurement of resting position in standing was taken first (Figure 2). With the patient remaining in the relaxed standing position, the tool’s wings were placed on the halfway marks, and the body of the device was moved towards the spine until it touched the subject’s spinous process. The sitting hand press-up position was measured by placing two chairs with the backrests facing each other at shoulders width apart, and then prior to instructing the subject, the chairs were tested by researchers to ensure they could hold the bodyweight of the subject. Subjects were then instructed: “with one hand on the back of each chair press-up and support your bodyweight while pulling your knees up to a 90° angle and hold for five seconds.” Measurements were taken in the identical manner as in the resting position (Figure 3). Values were recorded to the nearest millimeter for both positions. Testing was done on consecutive days with different examiners.

Statistical Analysis
A level of statistical significance of p ≤ 0.05 was set for all analyses. Reliability was measured by calculating Intra Class Correlation Coefficients (ICCs). ICCs were
calculated to evaluate the intra- and inter-rater reliability of the scapular medial border posterior displacement measurements. Intra-rater reliability for each rater was based on the calculation of the ICC for each individual rater. Inter-rater reliability was established by calculating the ICC for all tests performed by all raters. The ICC is an appropriate measure for both the intra- and inter-rater reliability as it considers both consistency of and absolute agreement between paired observations.15

Results
Statistical assumptions of the data distribution and homogeneity of variances were met for all analyses. Scapular medial border posterior displacement in a resting position and during the sitting hand press-up test was measured on all 16 subjects. The scapular medial border posterior displacement measures between the rater 1 and 2 in standing position were $1.1 \pm 0.63$ cm and $1.09 \pm 0.60$ cm vs. $1.15 \pm 0.65$ cm and $1.18 \pm 0.61$ cm for the 1st and 2nd testing sessions. The values in a sitting hand press up position between the raters were $1.36 \pm 0.60$ cm and $1.36 \pm 0.60$ cm vs. $1.31 \pm 0.64$ cm and $1.33 \pm 0.63$ cm for the 1st and 2nd measurements (Table 1). Intraclass correlation coefficients (2,1) for intra-rater reliability in the resting position were .97 (95% CI of .91 to .98) and .99 (95% CI of .97 to .99) for raters 1 and 2, respectively. ICCs for intra-rater reliability in the sitting hand press-up test were .95 (95% CI of .86 to .98) and .98 (95% CI of .95 to .99) for raters 1 and 2. The ICC for inter-rater reliability was .89 (95% CI of .81 to .96) for the resting position and .88 (95% CI of .80 to .96) for the sitting hand press-up test (Table 2). The standard error of measurements (SEM) of the scapular medial border posterior displacement for the rater 1 and 2 in the resting position and the sitting hand position were 0.15 and 0.16 cm (Table 2). The SEM for the scapular medial border posterior displacement between the raters in the resting and sitting hand position were 0.16 and 0.15 cm (Table 2).

DISCUSSION
The results of the study showed that by using the method proposed, the scapular medial border posterior displacement demonstrated acceptably high clinical intra- and inter-rater reliability. Portney and Watkins16 have suggested that ICC values above .75 are indicative of good reliability and those below .75 should be considered as poor to moderate. According to the suggestion made by the same authors, reliability of clinical measurements should exceed .90 to ensure reasonable validity.16 All the ICC measurements in this study were close to or above .90, which

Table 1. Mean values and standard deviations for scapular medial border posterior displacement measurements.

<table>
<thead>
<tr>
<th>Tester</th>
<th>Testing Position</th>
<th>1st measurement (cm)</th>
<th>2nd measurement (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rest</td>
<td>1.1±0.63</td>
<td>1.09±0.60</td>
</tr>
<tr>
<td></td>
<td>Press up</td>
<td>1.36±0.60</td>
<td>1.36±0.60</td>
</tr>
<tr>
<td>2</td>
<td>Rest</td>
<td>1.15±0.65</td>
<td>1.18±0.61</td>
</tr>
<tr>
<td></td>
<td>Press up</td>
<td>1.31±0.64</td>
<td>1.33±0.63</td>
</tr>
</tbody>
</table>
indicates that they have met the threshold for both good reliability and could offer clinical utility as a measurement procedure. Standard error of measurements (SEM), which is non-relative measure of reliability provides the clinician with an estimation of the error associated with a measurement in the units used to make that measurement. The SEM for all measurements ranged from 1.5 mm to 1.6 mm at rest and during the sitting tests (muscles engaged) demonstrating very low measurement error.

In a clinical evaluation a clinician looks for a lifting of the medial border of the scapula away from the spine/rib cage during shoulder motion to confirm a diagnosis of scapular medial border posterior displacement. Current clinically available testing procedures quantify motion laterally away from the spine (LSST), or upward and downward rotation of the scapular but not posterior motion away from the spine. By combining these three tests, an examiner may be able to get a more clear picture of scapular motion without the use of expensive and time consuming three-dimensional motion capture analysis. The test described in this paper measures medial border posterior displacement without the use of an expensive motion capture device. Unlike motion capture the test used in the study is still a two dimensional test which presents certain limitations in representing scapular motion, however, it was determined to be a reliable measure of medial border posterior displacement when used at the midpoint along the medial border of the scapula. This measure at this location along the medial border eliminates inconsistency in the measurement technique due to anterior and posterior tilt. It also reduces the amount of soft tissue interference in the measurement that could be influenced by muscle size differences over the superior angle.

The availability of a reliable and valid clinical method for determining the amount of scapular medial border posterior displacement in athletes would be an invaluable tool for accurate evaluation of the stabilizing structures of the shoulder. This clinical measure would allow for pre- and post-activity measurements as well as multiple measures throughout the course of a season or throughout the progression of a rehabilitation program. In evaluating the extent of medial border posterior displacement it is important to obtain measures both at rest and with muscular activity. Currently, inexpensive and clinically feasible options such as the scapular slide test are limited to resting and semi-dynamic measures of scapular position in upward rotation. The test presented here shows significant promise for use of an inexpensive clinical device that would allow for testing of scapular internal rotation, both at rest and semi-dynamically.

A larger scale study of between examiner and between-trials reliability is warranted to better establish the reliability of this innovative method and device. Future studies should use this new method on pathological populations in order to determine if significant relationships exist between the amount of scapular medial border displacement and injuries. Ludewig and Cook, Myers et al. and Borsa et al. hypothesized that alterations in scapular position and movement may bear a direct relationship to scapular stability and the generation of muscular force production, however this relationship is still poorly understood. The authors of this paper believe that it is necessary to continue research into how alterations in scapular position and motion affect neuromuscular function of the shoulder complex and how it is related to shoulder injury and dysfunction.
CONCLUSION
The raters in this study demonstrated excellent intra-rater and good inter-rater reliability when assessing scapular medial border posterior displacement with the standardized measurement tool in both static and semi-dynamic testing positions. The reliable information obtained from the sitting hand press-up test may assist in the clinical assessment and documentation of athletes’ progress in the rehabilitation process, thereby enhancing rehabilitation providers’ ability to effectively measure the results of, adjust, and monitor treatment outcomes.

REFERENCES
ABSTRACT

Introduction: Chronic exertional compartment syndrome (CECS) is a condition that occurs almost exclusively with running whereby exercise increases intramuscular pressure compromising circulation, prohibiting muscular function, and causing pain in the lower leg. Currently, a lack of evidence exists for the effective conservative management of CECS. Altering running mechanics by adopting forefoot running as opposed to heel striking may assist in the treatment of CECS, specifically with anterior compartment symptoms.

Case Description: The purpose of this case series is to describe the outcomes for subjects with CECS through a systematic conservative treatment model focused on forefoot running. Subject one was a 21 y/o female with a 4 year history of CECS and subject two was a 21 y/o male, 7 months status-post two-compartment right leg fasciotomy with a return of symptoms and a new onset of symptoms on the contralateral side.

Outcome: Both subjects modified their running technique over a period of six weeks. Kinematic and kinetic analysis revealed increased step rate while step length, impulse, and peak vertical ground reaction forces decreased. In addition, leg intracompartmental pressures decreased from pre-training to post-training. Within 6 weeks of intervention subjects increased their running distance and speed absent of symptoms of CECS. Follow-up questionnaires were completed by the subjects at 7 months following intervention; subject one reported running distances up to 12.87 km pain-free and subject two reported running 6.44 km pain-free consistently 3 times a week.

Discussion: This case series describes a potentially beneficial conservative management approach to CECS in the form of forefoot running instruction. Further research in this area is warranted to further explore the benefits of adopting a forefoot running technique for CECS as well as other musculoskeletal overuse complaints.

Key Words: anterior compartment syndrome, fasciotomy, forefoot running, shin splints.

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IRB approval was granted for the study protocol by Keller Army Community Hospital on 5 OCT 2010
This research was conducted at the United States Military Academy, West Point, NY. At the time of the research, MAJ Diebal was completing a post professional sports medicine physical therapy residency under the mentorship of Dr. Gerber as well as completing her 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 Army, the Department of Defense, or the United States Government.

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INTRODUCTION
Since the 1970’s the popularity of aerobic exercise has increased tremendously. Running has long been a primary popular choice of aerobic exercise for many people and boasts several positive health benefits. It can be performed virtually anywhere without any special equipment, can complement most physical training programs, and can improve aerobic endurance with three 30 minute training sessions per week. As the number of individuals participating in leisurely jogging and running activities has increased, the incidence of injuries has also increased.

In an effort to prevent, treat, and reduce running injuries, a current trend in rehabilitation has centered on modifying running technique. Several running techniques that have recently gained popularity are Chi Running, Barefoot Running, Evolution Running, and the Pose Method. These running styles are similar in the sense that they aim to eliminate the initial heel strike at ground contact by promoting a forefoot strike upon impact. While much more research is needed to determine if adopting such a running style can help prevent injuries, several authors have demonstrated that a significant reduction of ground reaction forces can occur if the heel strike is eliminated at initial impact. Research has not been thoroughly conducted to determine what musculoskeletal conditions would respond favorably or not so favorably to changing running styles. Theoretically, adopting a forefoot running style would be best suited for those conditions that could benefit from reduced ground reaction forces while running (i.e., stress reactions/fractures, anterior knee pain, back pain, etc.). This case series presents preliminary data which suggests that chronic exertional compartment syndrome (CECS) is one musculoskeletal condition that may respond positively to adopting an alternate running style.

CECS is defined as a condition that causes lower leg pain and disability during exercise in the presence of increased intramuscular pressure in a closed fibrososseous space. This condition is most prevalent in young adult athletes and occurs with increased frequency among members of the military. The exact cause of CECS remains unclear but it is speculated that the pressure increase is due to arterial spasm, capillary obstruction, arteriovenous collapse, venous outflow obstruction, muscle hypertrophy, fascial inflexibility, or a release of protein bound ions. The high pressure may cause vascular occlusion and decreased tissue perfusion which may lead to ischemic pain that often occurs bilaterally. The anterior compartment is the most common location for CECS to occur, with runners accounting for 69% of all cases. The anterior compartment is bordered by the tibia, fibula, interosseous membrane, and the anterior intermuscular septum. It consists of the tibialis anterior muscle and anterior tibial artery, extensor digitorum longus, extensor hallucis longus, fibularis tertius muscles, the anterior tibial artery, and the deep fibular nerve. Diagnosis of this condition is difficult due to the lack of clinical signs and symptoms. History and physical examination alone are often considered inadequate for the diagnosis of CECS. Intracompartamental pressure measurements confirm the diagnosis of CECS and help differentiate it from other conditions causing exercise induced pain. Pedowitz et al developed intramuscular pressure thresholds using a slit catheter to further assist in the diagnosis of CECS. For those suffering from CECS, running activities present a significant problem. As the compartment pressure increases, a person may develop lower leg pain, sensory abnormalities, and muscle weakness which eventually results in a premature cessation of the activity. Upon cessation of the activity the compartment pressure decreases, pain subsides, and the functional examination returns to “normal”, typically within ten minutes. Recommended non-surgical management for CECS includes anti-inflammatory drugs, stretching, prolonged rest, decreasing or avoiding the problematic activity, orthotics, and massage. None of these conservative approaches have yielded consistently positive long term results; however, no randomized controlled studies exist in the literature to truly investigate conservative management techniques. If those with CECS do not desire to modify their activity level, the only effective treatment for this condition is surgical management in the form of a fasciotomy. While the majority of patients do well following surgery, approximately 3-17% of individuals undergoing fasciotomy experience less than favorable outcomes such as ankle pain, reoccurrence of symptoms, decreased sensation at the incision site, numbness at the lateral leg, hypersensitivity to touch, and paresthesias in the legs.
One conservative management approach that has not been investigated, but theoretically could assist those with anterior CECS, is altering running technique. Kirby et al found that anterior compartment pressures were significantly influenced by running style, reporting anterior compartment pressures were increased when a heel striking gait pattern was utilized. It has also been well documented that forefoot striking as opposed to heel striking causes a decrease in ground reaction forces, stride length, and ground contact time and an increase in step rate. To the authors’ knowledge, the modification of running technique as an intervention for CECS has not previously been investigated. Incorporating the use of a systematic instructional model, which focuses on landing on the forefoot as opposed to the heel, may assist in controlling the elevation of compartment pressures with running. If successful, this could allow those suffering from CECS the ability to run longer without symptoms and possibly reduce the need for fasciotomy.

The purpose of this case series is to describe the outcomes for two subjects with anterior CECS through the implementation of a systematic conservative treatment model focused on forefoot running.

CASE DESCRIPTION

Both participants were given a verbal explanation of the study protocol and provided written informed consent prior to testing. Approval was granted by the Institutional Review Board at Keller Army Community Hospital.

Case 1: A 21-year old female (154.9 cm, 52.6 kg) presented to physical therapy with a four year history of bilateral anterior and lateral lower leg pain that occurred while running. The patient reported leg symptoms while running that began predictably before 0.8 km resulting in pain and tightness, which progressively worsened to include numbness and pressure with pain throughout the exercise. She reported the ability to tolerate the leg pain for several kilometers if running on flat surfaces at a slower pace; however, she could tolerate less than 1 km if she ran up hills. She reported that upon cessation of running her symptoms would completely resolve within 5 to 10 minutes.

The initial physical examination at rest was unremarkable (i.e., full ankle and knee range of motion (ROM) and strength, no tenderness or compartment tightness to palpation, and full functional ability to squat and hop without symptoms). A running evaluation was conducted by real time observation using a commercial grade treadmill (LifeFitness, 97Ti, Franklin Park, IL). The patient ran at a self-selected pace of 11 km per hour, demonstrating a heel striking and over-striding gait pattern. The patient reported an onset of pain in the anterior and lateral aspect of both lower legs after running 3 minutes, at which time an audible and visual foot slap was observed for both lower extremities. After 0.8 km (5 minutes, 10 seconds), the patient reported a 6/10 pain on the left leg (2/10 on the right leg) and requested to end the session. A physical examination immediately following revealed an appreciable firmness and tenderness to palpation in both anterior compartments, and decreased dorsiflexion strength bilaterally (4+/5). Based on history and physical examination, a preliminary diagnosis of leg pain consistent with CECS was made.

The subject returned the following day for the collection of kinematic and kinetic running data. An instrumented treadmill was utilized (Kistler-Gaitway, Zurich, Switzerland) to assess variables illustrating running technique such as; step length, step rate, vertical ground reaction force (GRF), and impulse, (Table 1). Impulse is defined as the product of the...
magnitude of a force and its time of application. It is specifically the area under a vertical ground reaction force-time curve. In a third visit, pre- and post-exercise intracompartmental pressures of the anterior compartments were measured by an orthopedic surgeon (refer to Tables 6 and 7 for values) using a Stryker Intracompartmental Pressure Monitor (Side Port Needle, Kalamazoo, MI).\(^\text{20,43,44}\) Positioning of the knee, leg, and foot was standardized for all measurements. Post-exercise pressure measurements were taken at 1 minute following exercise cessation. Due to the elevation in post exercise intracompartmental pressure, the diagnosis of CECS was made by the orthopedic surgeon.

Physical therapy intervention was initiated that focused on modifying the patient’s running technique. The patient was instructed in a forefoot running technique on both land and treadmill, with the aim of eliminating the initial heel strike and consequently reducing ground reaction forces.\(^\text{7,45}\) Training included increasing her running step rate to 3 steps per second and using her hamstrings to pull her foot from the ground versus push her foot from the ground using the gastrocnemius.\(^\text{9}\) A digital metronome (Seiko, DM50S, Singapore) was also utilized to increase step cadence to 180 steps per minute. Focused training drills and exercises consisted of weight shifting, falling forward, foot tapping, high hopping, and running with a specialized belt (EZ Run Belt, Posetech.com) as described by Romanov (Figures 1-5).\(^\text{7,46}\) The subject also practiced running barefoot with verbal cueing to “run quietly” to eliminate the tendency to heel strike upon ground contact. Feedback was provided using video recorded from a

Figure 1. Weight Shifting—In this drill the patient focuses on shifting the pressure from the heels onto the forefeet to improve perception of how minute adjustments can dramatically change body weight during support.

Figure 2. Falling Forward—In this drill the patient focuses on falling forward while maintaining the running pose in front of a wall. Start close to the wall and move farther from the wall as comfort level increases.
commercial camera (Flip Video, Cisco, California) and placed on a personal laptop computer (MacBook Pro, Apple) to help demonstrate and correct running errors. This instruction was conducted 3 times a week for approximately 1 hour each and took place over the course of 6 weeks. The instruction initially consisted of the training drills listed in Figures 1-5 and then progressed to forefoot running intervals for distances of .25 km with a two minute walking period between intervals. Running endurance was gradually progressed as proper running form was maintained for longer distances between walking bouts. Instruction during the last 3 weeks of training mainly focused on improving running speed and endurance while maintaining proper form during running duration.

OUTCOMES
At 6 weeks post-intervention, the physical examination, including intracompartmental pressures, and the kinematic and kinetic treadmill measurements were repeated. The physical examination was unremarkable before and after running. The patient ran 5 km (26 minutes, 18 seconds) on the treadmill without any pain complaints; treadmill testing concluded at a predetermined distance of 5 km. The force plate treadmill measurements and the pre- and post-intracompartamental pressures of the anterior compartments are presented in Table 1 and Figure 6. She also completed a global rating of change (GROC) score at that time, rating herself as a 6 (a great deal better).
A follow-up questionnaire was completed at 7 months, at which time the subject reported the ability to run 12.87 km (including) hills without an increase of leg symptoms and she reported that she was training to run a marathon.

**CASE DESCRIPTION**

**Case 2:** A 21-year old male (172.7 cm, 97.4 kg) presented to physical therapy with complaints of bilateral anterior and lateral lower leg pain while running seven months status post two-compartment (anterior and lateral) right leg fasciotomies (to correct CECS). He stated that his pre-surgical symptoms returned on the right leg within two months following surgery and now has a new onset of pain and tightness in the left leg. The patient reported that his left leg was now worse than the right, and his overall pain caused him to stop running after approximately 5 minutes. He verbalized concern that he may need a surgery on the left leg. He reported complete reduction of symptoms within 5 minutes of rest.

Similar to the first case, the physical examination was unremarkable at rest. However, this patient had noticeably hypertrophied lower legs (calf musculature). A running evaluation, utilizing visual analysis, was conducted on a commercial treadmill at a self-selected speed of 10.5 km/hr, during which he demonstrated a heel striking gait pattern. After running for 2 minutes, 30 seconds, he reported pain and tightness in the right anterior and lateral lower leg. After 0.81 km (5 minutes, 14 seconds), the subject noted the onset of pain and tightness on the left side. After 1.56 km (9 minutes, 11 seconds), a foot slap was observed on the left side at which time he requested to stop the activity. Physical exam immediately following revealed an appreciable firmness and tenderness to palpation in both anterior compartments. He complained of pain in the legs with resisted dorsiflexion (5/5 strength) and with full passive plantar flexion. Kinematic and kinetic data was gathered along with pre- and post-exercise intracompartmental pressures of the anterior compartments (Table 2 and Figure 7). The patient was diagnosed with CECS by an orthopedic surgeon and the intervention of modifying his running technique was initiated.

The running instruction and training mirrored that provided during case one, emphasizing a forefoot running pattern, increasing the step rate to 3 steps per second, and use of the hamstrings to pull his foot from the ground while running.7

**OUTCOMES**

After 6 weeks, the physical examination, intracompartmental pressures, and instrumented treadmill measurements were repeated. The physical examination was unremarkable before and after running. The patient ran 4.02 km (21 minutes, 8 seconds) on the treadmill without complaints of leg pain; however,
The test was discontinued due to complaints of left foot arch pain. A subsequent physical exam of his foot and ankle was unremarkable. The kinematic and kinetic measurements and the pre- and post-intracompartamental pressures of the anterior compartments are provided in Table 2 and Figure 7. He also completed a GROC score at that time and rated himself as a 7 (a great deal better). After 2.5 months he reported he was able to run 6.43 km without pain. On a follow-up questionnaire at 7 months he reported running distances of 6.43 km pain-free 3 times a week.

**DISCUSSION**

This case series presents two subjects with CECS whereby altering running mechanics to a forefoot striking technique was the primary intervention. The subjects had favorable results which allowed them to return to pain-free running activity without surgical intervention. The change in running technique was demonstrated by increased step rate and decreased impulse, GRF, and step length (Tables 1 and 2). Post-exercise compartment pressures were lower by as much as 30% in some cases (Figures 6 & 7). In addition, these two subjects, who could not run over 1 km without severe symptoms prior to the intervention, could now run 4 and 5 km with minimal difficulty.

Successful rehabilitation for CECS has historically been challenging. Physical therapists typically perform patient examinations looking for impairments that can be addressed through therapeutic exercise, various modalities, or manual therapies. CECS is a unique condition whereby it is commonly very difficult to find impairments related to a patient's symptoms. Although research is certainly limited, this is potentially one reason why attempts at non-surgical management with anti-inflammatory drugs, stretching, prolonged rest, decreasing or avoiding the problematic activity, orthotics, and massage have largely proved unsuccessful. In these two cases, the selected intervention was not based on any specific impairment observed or measured during the physical examination. Rather, it was based on observing a heel striking gait pattern with running and the theory that decreasing anterior compartment muscle activity could potentially be beneficial for this condition.

There are several possible reasons to explain how the forefoot running training technique may assist those with CECS. Gershuni et al and Tsintzas et al found a significant increase in the anterior compartment pressures of healthy individuals in the full ankle dorsiflexion and full knee extension positions.47,48 The position of full knee extension coupled with full ankle dorsiflexion is consistent with the typical heel strike technique used by runners at initial contact. In addition to a potentially more favorable foot position at initial ground contact (less ankle dorsiflexion), eliminating the heel strike upon ground contact by replacing it with a forefoot strike may reduce the eccentric muscle activity of the anterior leg compartment musculature and therefore mitigate the increase of anterior compartment pressures and symptoms of CECS during running.21,47,48 As previously noted, Kirby et al reported that anterior compartment pressures were increased when a heel striking gait pattern was utilized as opposed to a neutral or forefoot running gait.15 Therefore, a forefoot running technique may favorably reduce the variables that contribute to the onset of CECS symptoms and reduce the necessity for surgical management for this condition.

The cases presented in this paper are interesting for several reasons. In case one, the patient quickly adapted the new forefoot running technique. Compared to pre-intervention measures her impulse, ground reaction forces, and step length decreased by approximately 5%, 7%, and 9% respectively. Step rate
increased by approximately 9%. It is possible that altering these aspects of running mechanics favorably affected her during her rehabilitation as she was able to return to running without pain or limitation in 6 weeks.

Case two differs from case one in that he previously had a fasciotomy on his right leg, in which his CECS symptoms returned approximately 2 months after surgery when he resumed running. As his running distance progressed, his left leg became more symptomatic than the right, and his bilateral leg symptoms were consistent with CECS. Adjusting running technique and learning to pull the foot from the ground was challenging for this subject. No specific functional deficits were identified as contributors to this challenge. However, it is the authors' experience that some individuals have a more difficult time than others while attempting to perform a forefoot running technique. A great deal of attention to detail and video feedback was necessary for this patient. Ultimately, he avoided fasciotomy on his left leg and a revision fasciotomy on his right leg, and his running distance has continued to increase.

Ultimately, no cause and effect relationship can be inferred by the results of case report research. Interpretation of the current findings presents challenges related to the fact that pressure measurements post-intervention performed at rest and 1 minute following running could be considered elevated according to previous researchers. For example, over 20 years ago, Pedowitz et al published that resting values higher than 15 mmHg and post exercise values over 30 mmHg were indicative of CECS with the caveat that elevated pressures without symptoms of CECS would not be considered a positive test. Resting pressure values in these 2 subjects ranged from 20 mmHg to 32 mmHg while post running pressures ranged from 36 mmHg to 63 mmHg. Direct comparison to previously reported values should be cautioned, as conflicting values have been reported by several studies, with reports of normal intracompartmental pressures varying by up to 500% It has also been documented that pressure varies with the depth of the catheter placement, which is difficult to control. These variables could explain the fact that resting pressures at 6 weeks were elevated compared to the resting pressures at baseline. We are unable to make direct comparisons of our pressure data to findings reported by Pedowitz et al due to the fact that their study used a slit catheter to establish CECS pressure criteria, and the current report describes pressures obtained via a side-port needle catheter. Despite elevated pressure readings, the subjects were asymptomatic. Therefore, they no longer met the diagnostic criteria for CECS; elevated pressures in the presence of other clinical findings.

Caution and careful instruction may be required to avoid undesired complications when one attempts to alter his or her current running style. Common complications include achilles tendonopathy, plantar fascia pain, gastrocnemius soreness, blisters, iliobibial band syndrome, and anterior knee pain. Running errors while attempting to transition to a forefoot running gait pattern typically contribute to these musculoskeletal complaints and can be greatly reduced by careful supervision and correction during training. Similar to most new exercise programs, proper form and gradual progression in time and intensity must be emphasized. Additionally, patients presenting with leg pain should be evaluated by a credentialed medical provider.

While no generalizations or intervention recommendations can be made from this case series, it does illuminate the need for further research in this area. For those patients with CECS, adopting a forefoot running style may lead to an increased tolerance for running and therefore potentially decrease the need for surgical management of this condition. The authors are currently conducting a clinical trial with a larger sample size to further explore the effectiveness of forefoot running on those diagnosed with CECS.

REFERENCES
4. Edmundsson D, Toolanen G, Sojka P. Chronic compartment syndrome also affects nonathletic


ABSTRACT

Purpose/Background: Abnormalities in glenohumeral rhythm and neuromuscular control of the upper trapezius (UT), middle trapezius (MT), lower trapezius (LT) and serratus anterior (SA) muscles have been identified in individuals with shoulder pain. Upper extremity diagonal or proprioceptive neuromuscular facilitation (PNF) patterns have been suggested as effective means of activating scapular muscles, yet few studies have compared muscular activation during diagonal patterns with varying modes of resistance. The purpose of this study is to determine which type of resistance and PNF pattern combination best elicits electromyographic (EMG) activity of the scapular muscles.

Methods: Twenty one healthy subjects with no history of scapulohumeral dysfunction were recruited from a population of convenience. Surface electrodes were applied to the SA, UT, MT and LT and EMG data collected for each muscle as the subject performed resisted UE D1 flexion, UE D1 extension, UE D2 flexion and UE D2 extension with elastic resistance and a three pound weight.

Results: No significant differences were found between scapular muscle activity during D1 flexion when using elastic resistance and when using a weight. UT, MT and LT values were also not significantly different during D2 flexion when using elastic resistance vs. using a weight. The activity of the SA remained relatively the same during all patterns. The LT activity was significantly greater during D2 flexion with elastic resistance than during the D1 flexion and D1 extension with elastic resistance. MT activity was significantly greater during D2 flexion with elastic resistance as compared to all other patterns except D2 flexion with a weight. UT activity was significantly greater during flexion patterns than extension patterns.

Conclusions: The upper extremity PNF pattern did significantly affect the mean UT, MT and LT activity but was not found to significantly affect SA activity. The type of resistance did not significantly change muscle activity when used in the same diagonal patterns.

Key Words: elastic resistance, electromyography, proprioceptive neuromuscular facilitation, scapular musculature

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INTRODUCTION
In the normal shoulder complex with full function, the humerus and the scapula must move in a predictable pattern or demonstrate “a normal scapulohumeral rhythm.” When viewed in the scapular plane, a position midway between a sagittal and frontal plane, scapulohumeral rhythm is a progressive upward rotation of the scapula accompanied by a decrease in internal rotation and movement from an anteriorly tipped position to a posteriorly tipped position of the scapula as the humerus elevates during overhead movement. In a patient with dysfunction of the shoulder complex, scapulohumeral rhythm may be altered and has been shown to be present in patients with shoulder pathologies such as impingement, shoulder instability, and frozen shoulder syndromes. Given that dysfunction of the shoulder complex is estimated to affect approximately 7-36% of the population, a clear understanding of shoulder movement is important to health care professionals and their patients.

The presence or absence of normal scapulohumeral rhythm is largely dependent on the appropriate firing pattern of the muscles providing dynamic support about the shoulder complex. Muscles which are crucial to scapular movement include the upper trapezius, middle trapezius, lower trapezius, rhomboids, and serratus anterior muscles while the rotator cuff muscles (supraspinatus, infraspinatus, teres minor, and subscapularis) are important to humeral stability. Some evidence documents altered recruitment in the scapular stabilizing musculature in patients with shoulder pathologies but it is unclear as to whether the alterations in patterns precede the development of the pathology or occur as a result of the altered mechanics of the shoulder complex.

Physical therapy interventions designed to restore normal scapulohumeral rhythm frequently include exercises that focus on the scapular muscles. Movements recommended for strengthening the upper trapezius include rowing, the military press and shoulder shrugging while exercises that maximize EMG activity of the middle trapezius include horizontal abduction, shoulder extension, overhead arm raise in a prone position, and rowing. Shoulder abduction, rowing, horizontal abduction and overhead arm raises in prone or sidelying maximize lower trapezius activity while shoulder flexion, shoulder abduction, scapular plane abduction above shoulder height maximize serratus anterior activity.

Diagonal patterns of the upper extremity are often included in exercises thought to affect recruitment of the scapular muscles. Traditional proprioceptive neuromuscular facilitation (PNF) interventions focus on functional diagonal patterns of movement to improve both muscular strength and flexibility as well as utilize sensory cues such as cutaneous, visual, and auditory stimuli to improve neuromuscular control and function. Incorporation of the elementary movements of these patterns into shoulder rehabilitation programs may also be effective in increasing scapular muscle activation.

While the selection of the type of exercise movement or pattern to incorporate into a rehabilitation program to activate the desired muscle(s) is an important consideration, the selection of resistance to achieve the appropriate intensity and type of muscle activation is also vital. Training intensities of greater than 60% are often recommended and multiple methods of resistance exist for achieving that intensity. Common in both clinical and home settings are the use of free weights and/or the use of elastic tubing to provide the resistance needed to approach the prescribed level of muscle activation. Traditionally, weights have provided concentric and eccentric resistance with torque on a muscle varying with positional changes. Use of elastic tubing has been suggested as an alternative to weights due to low cost, portability, and increasing resistance that occurs throughout the exercise movement. Andersen et al used surface electromyography (EMG) to compare the effects of free weights and elastic tubing on the upper trapezius, middle deltoid, and infraspinatus EMG output. The authors reported that during a standing lateral raise of the arm and during sidelying external rotation of the glenohumeral joint, normalized EMG output was not significantly different between conditions using free weight or elastic tubing. However, Page and associates suggest that elastic resistance may have some advantages over free weights. They measured isokinetic torque output at 60º/sec during a D2 flexion and extension pattern and found greater output following an exercise program where subjects trained using elastic resistance as compared to those who trained using free weights.
Because diagonal patterns are commonly used clinically to recruit scapular muscles and resistance during these patterns can be applied using weights or elastic resistance, studying both methods of resistance during diagonal patterns would be of assistance when choosing an exercise to strengthen selected scapular muscles. The aim of this study was to investigate the level of muscle activation that occurred in the scapular muscles during diagonal patterns using weights and elastic resistance, as measured by surface EMG. The null hypothesis was that the levels of EMG activity of the scapular muscles would be similar in all patterns with both types of resistance.

**Methods**

**Participants**

The study was performed on a population of convenience. Twenty-one volunteers (6 male and 15 female) whose age ranged from 21-37 years (mean = 25.3 yrs) participated in the study. All subjects signed an informed consent form that had been approved by the Institutional Review Board at the authors' research facility. Subjects were not compensated for participation. Information regarding subject medical history was obtained through a self-report survey and questioning by the investigators. Exclusion criteria included a history of cardiovascular problems requiring medical treatment, and any individuals with medical conditions or problems which would prevent them from putting forth maximal effort. Subjects who reported pain in the shoulder or scapular region within the last 6 weeks; those who had a history of biomechanical problems of the shoulder including dislocation, subluxation of the glenohumeral joint or dyskinesis of the scapula; had a history of rotator cuff tear or repair, unhealed fracture, current nerve damage to the shoulder; or were currently undergoing diagnostic testing or treatment for shoulder problems were excluded.

**Procedures**

As a warm up, subjects rode an upper body ergometer for 4 minutes. A reviewer then led the subject in the performance of stretches of the neck and shoulder. Stretches were held for 15 seconds at the end ranges of right and left cervical sidebending (to stretch the upper trapezius), scapular protraction (to stretch the rhomboids and middle trapezius), shoulder horizontal adduction (to stretch the posterior capsule), shoulder horizontal abduction (to stretch the pectoralis major), shoulder flexion with the elbow flexed (to stretch the triceps) and shoulder extension with the elbow extended (to stretch the biceps).

The skin was cleaned using an alcohol wipe and then EMG surface electrodes were placed on the upper trapezius, middle trapezius, lower trapezius, and serratus anterior muscles on the self-reported non-dominant shoulder of the subjects as described by Michener et al. Manual muscle tests (MMTs) were performed on the upper trapezius, middle trapezius, lower trapezius, and serratus anterior muscles to determine maximal volitional contraction of the non-dominant arm. The upper trapezius MMT was performed as described by Kendall et al. In a sitting position, the subject elevated the arm and posterolaterally extended the neck as the examiner applied pressure against the shoulder toward depression and against the head toward anterolateral flexion. The MMT for the middle trapezius was performed with the subject prone, arm abducted to 90º, shoulder laterally rotated and the scapula adducted. The examiner applied pressure to the arm, proximal to the elbow, in a downward direction. The lower trapezius MMT was performed with the subject prone, arm in 145º of abduction, shoulder laterally rotated and the scapula adducted. The examiner applied pressure on the arm proximal to the elbow in a downward direction. The serratus anterior MMT was performed with the subject sitting in a chair with the arm flexed to 125º. As the examiner monitored the inferior angle of the scapula for internal rotation or anterior tipping of the scapula, pressure was applied on the arm, proximal to the elbow in a downward motion. Pressure was adjusted throughout the test for any changes in scapular position to assure that the subject held the appropriate position. Each MMT was performed three times with maximal resistance given for 5 seconds with a 20 second rest period between tests. The order of testing was randomized prior to subject recruitment using a randomization table. The mean EMG activity of the three trials was used to determine the maximal volitional contraction. All EMG data was collected using a Biometrics DataLink (Biometrics Ltd, Gwent, United Kingdom).
Following the MMTs, subjects were instructed in how to perform D1 and D2 flexion and D1 and D2 extension PNF patterns as per typical PNF theory. To perform the D1 flexion pattern, the subject started with the arm down by the ipsilateral side and brought it up toward the ear of the contralateral side moving through glenohumeral motions of flexion, adduction, and external rotation. The subject performed the D1 extension pattern by starting with their arm by the contralateral ear and bringing it down toward the ipsilateral side of the waist moving through the glenohumeral motions of extension, abduction, and internal rotation. The pattern of D2 flexion was performed with the subject starting with their arm on the contralateral side of their waist and bringing arm up above the ipsilateral side of the head, a movement which consisted of glenohumeral flexion, abduction, and external rotation. D2 extension was performed with the subject starting with their arm above the ipsilateral side of the head and bringing it down toward the contralateral waist, a motion that involved extension, adduction and internal rotation. Throughout all patterns subjects were instructed to keep the elbow in as much extension as possible and all instruction and trials were performed in a sitting position. Subjects continued to receive instruction until they could complete the patterns independently and without verbal cues.

Following mastery of the patterns, the subjects performed the patterns without resistance and then progressed to resistance using blue elastic resistance (The Hygenic Corporation, Akron OH). Blue elastic resistance was utilized by Lister et al17 and represents the midrange of resistances. To standardize the length of the elastic resistance for each individual, the distance between the anchor and the hand was equal to the length of the distance between the floor and the greater trochanter as measured with the individual in a standing position. For flexion patterns, one end of the elastic resistance was anchored to the floor by a research assistant and the other end held by the subject (see Figure 1 for D1 flexion with elastic resistance, see Figure 2 for D2 flexion with elastic resistance). For extension patterns, one end of the elastic resistance was attached above the subject to an adjustable ceiling bracket and the other end held in the hand (see Figure 3 for D1 Extension with elastic resistance, see Figure 4 for D2 Extension with elastic resistance). At the start of the extension pattern with the arm in a position of flexion, abduction and external rotation, the length of the elastic resistance between the bracket and the hand was adjusted to equal the measurement.
of the torso (floor to greater trochanter) taken previously. Each pattern was performed three times at a self selected speed with a 20 second rest between each repetition.

In addition to elastic resistance, subjects performed the D1 flexion and the D2 flexion patterns with a three pound dumbbell. Because the goal of this study was to measure activation of the scapular during common exercises and not to result in muscle fatigue, the weight of the dumbbell was selected to avoid excessive loading of the rotator cuff. Carson\textsuperscript{18} cautions against utilization of weights over 5 pounds due to stress on the rotator cuff and advocates weights of one through 5 pounds for specific rotator cuff rehabilitation exercises. To duplicate typical clinical applications without rotator cuff fatigue, a midpoint of this suggested range (3 pounds) was used by all subjects in this study. Patterns performed with a weight involved the same motions as described above (see Figure 5 for D1 flexion with a weight and see Figure 6 for D2 flexion with a weight) with the subjects completing three trials of each pattern with a 20 second rest between each trial.

Similar to the MMT, the order for patterns and resistance was randomized before beginning the study using a randomization table. All data was collected during a single session.

**Data Reduction**

Following collection, all raw EMG signals were full-wave rectified and processed using a root-mean-square algorithm with a 4-ms moving window. The mid three second time period of each five second MMT was recorded for each trial and the three trials averaged to provide the MVC for each muscle. The start and stop of each resisted activity was marked on the processed EMG signal and the mean EMG activity of each muscle during that time was recorded. To normalize values during the exercises, the EMG value during each exercise trial was expressed as a percent of the MVC value recorded during MMT (\%MVC). The \%MVC for each of the three trials was averaged and used for analysis.

**Statistical Methods**

Separate one way ANOVAs were performed for UT, MT, LT and SA muscle activity to examine the differences in the percent maximal contractions between exercises. When a significant effect (p < .05) was found, comparisons of least square means with Bonferroni adjustment were completed to compare the various patterns and identify significant differences due to the
type of pattern and the type of resistance used. Further analysis on each of the percent mean values was completed to examine additional factors that could have influenced the muscle activity including pattern, body mass index (BMI), age and gender. Backward regression analysis was used to further explain differences in the percent maximal activity of each of the scapular muscles. All analyses were completed using SAS Version 9.1 (SAS Institute Inc., Cary, NC).

Results

Subject demographics are found in Table 1. Mean age was 25.4 years and the majority of the subjects were right hand dominant. The average BMI of 25.3 for the males is slightly higher than the 50th percentile of American males while the average BMI for females (22.6) falls within the normal range as proposed by the Centers for Disease Control and Prevention. Mean ± standard error of the mean (SEM) values of the percent maximal volitional contraction (PMVC) for each muscle during each pattern are presented in Table 2.

Upper Trapezius

One way ANOVA tests confirmed that upper trapezius %MVC values were significantly affected by pattern (p=0.00). There were, however, no significant differences between the upper trapezius %MVC during D1 flexion with a weight and during D1 flexion with elastic resistance. Similarly there were no significant differences between %MVC of the upper trapezius between D1 and D2 patterns, D1 flexion with a weight was comparable to D2 flexion with a weight; D1 flexion with elastic resistance was comparable to D2 flexion with elastic resistance; and D1 extension with elastic resistance was comparable to D2 extension with elastic resistance. The %MVC of the upper trapezius, however, did show significant variation in activation between extension and flexion patterns. The %MVC of the upper trapezius during D1 extension with elastic resistance and during D2 extension with elastic resistance were both significantly less (p=0.00) than D1 and D2 flexion with elastic resistance while only D2 extension with elastic resistance was significantly different than D2 flexion with a weight (see Figure 7).

The additional factors of BMI, gender, and age were examined in order to determine their potential effects on UT mean EMG output values. A MANOVA and regression analysis were used to examine all data, demonstrating that BMI (p=0.00) and gender (p=0.04), independent of pattern, were significantly associated with UT mean values. As illustrated in Figure 8, female UT EMG activity was significantly greater than male activity during flexion patterns with elastic resistance.

Middle Trapezius

Type of exercise significantly affected the %MVC output produced by the middle trapezius (p=0.00) with the differences associated with the pattern, but not the type of resistance. There were no significant differences in EMG output between the flexion patterns when subjects used different types of resistance; D1 flexion with a weight was comparable to D1 flexion with elastic resistance and D2 flexion with a weight was comparable to D2 flexion with elastic resistance. Similarly, output during D1 extension with elastic resistance was not significantly different from D2 extension with elastic resistance. However, there were significant differences between the %MVC output of the middle trapezius when different patterns were
performed. D1 flexion with a weight was significantly less than D2 flexion with a weight and D1 flexion with elastic resistance was significantly less than D2 flexion with elastic resistance (p = 0.00). In a comparison of flexion and extension patterns, the %MVC output of the middle trapezius was significantly greater during D2 flexion with elastic resistance than during D1 or D2 extension with elastic resistance. In contrast, D1 extension with elastic resistance and D2 extension with elastic resistance were not significantly different than D1 flexion with elastic resistance, D1 flexion with a weight, or D2 flexion with a weight (p = 0.00).

Regression analysis revealed that age (p = 0.78), gender (p = 0.11) and BMI (p = 0.46) were not significantly associated with middle trapezius %MVC output during the exercises.

**Lower Trapezius**

Similar to the other parts of the trapezius, there were no significant differences between the %MVC output of the lower trapezius when similar patterns were performed with different types of resistance. D1 flexion with a weight was similar to D1 flexion with elastic resistance and D2 flexion with a weight was similar to D2 flexion with elastic resistance. However, the lower trapezius %MVC activity was significantly less during D1 flexion with elastic resistance and D2 flexion with elastic resistance (p = 0.05). Likewise, lower trapezius %MVC activity during D1 flexion with a weight was also significantly less than D2 flexion with a weight (p = 0.05). The extension patterns did not significantly vary between D1 extension with elastic resistance and D2 extension with elastic resistance. As with the middle trapezius, regression analysis revealed that age (p = 0.17), gender (p = 0.39) and BMI (0.88) were not significantly associated with lower trapezius %MVC output during the exercises.

**Serratus Anterior**

Unlike the other scapular muscles, the PNF pattern did not significantly affect the serratus anterior %MVC output. There were no significant differences
between %MVC output during any patterns or between the types of resistance (p=0.85). Values for the serratus anterior %MVC output had a relatively narrow range with a low of 42.5% of the MVC during D1 extension with elastic resistance to a high of 50.0% of the MVC during D1 flexion with elastic resistance. Although the type of pattern and resistance did not explain variations in serratus anterior %MVC, regression analysis did reveal that gender was a significant factor (p = 0.00) in explaining differences among SA values.

DISCUSSION

The use of elastic resistance and free weights during shoulder exercises is widely recommended as part of shoulder rehabilitation programs yet little evidence is available to guide the clinician in determining which type of resistance or pattern of exercise may be optimal. The results of this study indicate that the pattern of the exercise chosen to be performed during shoulder complex diagonal exercises may be more crucial to the muscular activity produced by the scapular muscles than the selection of a weight or of elastic tubing as the type of resistance. In the current study, the %MVC output was not significantly different for any of the scapular muscles tested when a weight was used versus elastic resistance. However, the different diagonal patterns did alter the EMG output of the various portions of the trapezius muscle, indicating that attention be paid to the type of diagonal pattern that is selected.

The finding that the %MVC of the scapular muscles was similar when using a weight and when using elastic resistance is consistent with past studies. In the current study, this was demonstrated when performing PNF diagonal patterns of the upper extremity. While little research exists which directly compares two types of resistance during diagonal patterns several studies have compared the output of muscles when exercising with weights and with elastic resistance. Measuring EMG output, Andersen et al reported no significant differences in the trapezius, medial deltoid, or infraspinatus activity when subjects performed a lateral raise with a dumbbell and with elastic tubing, demonstrating only an increase in activity as the resistance of both were increased. Measuring torque output using an isokinetic dynamometer, Page et al also found no difference in the production of eccentric torque at faster isokinetic speeds (180°/sec) in a group of subjects trained with dumbbells when compared with a group of subjects trained with elastic resistance. Differences in torque output were reported at the slower speed of 60°/sec suggesting a varied effect of exercising with elastic resistance and exercising with weights. The use of isokinetic torque production by Page and associates as an outcome measure is difficult to compare to the isolated EMG %MVC output of specific scapular muscles used in the current study. In addition, it is difficult to determine if isolated scapular activity would show similar or different results after a training period. Further investigation, however, of the changes in the scapular muscle %MVC outputs after training with various resistive methods is warranted.

Differences in scapular muscle EMG activity when using cuff weights versus theraband were reported by Lister et al. They reported significantly greater activity of the upper trapezius, lower trapezius, and serratus anterior during shoulder flexion to 90° and shoulder abduction to 90° when elastic resistance (blue) was used as opposed to a cuff weight (1.1 kg). While the amount of resistance may be similar between the current study and the study by Lister et al, the motions which were examined and the methods used to normalize EMG values differed. The previous study modified traditional manual muscle tests for the lower trapezius and the serratus anterior by performing both in standing while the current study utilized the descriptions from Kendall et al. Such a change could alter the percent of the MVC output and prevent a direct comparison between the values reported in that study and the current investigation.

Values of the %MVC output for the scapular muscles found in this study ranged from a low of 15.9% of the MVC of the middle trapezius during D1 extension with theraband to a high of 68.5% of the MVC of the upper trapezius during D2 flexion with elastic resistance. In a 1992 study by Mosely et al, elevation of the humerus in the scapular plane resulted in %MVC values of 54%, 60%, 91% and 84% for the upper trapezius, lower trapezius, middle serratus anterior and lower serratus anterior respectively when using a self-selected free weight resistance which varied between 3 and 30 pounds. As expected,
the output produced by Mosley’s subjects are not similar to the 53.2%, 32% and 44.6% for the upper trapezius, lower trapezius and serratus anterior found in this study where the resistance was limited to one level of elastic resistance and the pattern involved different arm movements at the shoulder complex. Although the humeral positions were not monitored in the current study, efforts were made to assure the subject completed the pattern in a true diagonal and not into positions of full flexion or abduction. Movement out of diagonal planes could potentially alter the amount work required by the scapula and influence the stabilization efforts required to maintain its position. Differences in muscle activity during elevation in the scapular plane and D2 flexion would be expected.

Myers et al studied a movement that was multiplanar.10 Referred to as throwing acceleration, this movement started with the glenohumeral joint in full external rotation and abduction with the elbow at 90° of flexion. Elastic tubing was held in the hand and surface EMG recordings were taken as the subject moved the arm across the body as in the acceleration phase of throwing and then returned the arm to the original position. Described by the investigators of that study as being a D2 flexion pattern, measurements were expressed as %MVC which was determined by performing maximal volitional contractions of each muscle prior to the measurement during exercise. The EMG activity for the serratus anterior was reported to be 55.5% of the MVC.10 This is slightly higher than the amount recorded in the current study but as indicated above, the starting and ending positions were different as was the resistance used during each study. Ekstrom et al also reported %MVC of the trapezius and serratus anterior muscles in a position similar to D2F. After determining a five repetition maximum (5 RM) for each subject, each subject lifted 85%–90% of their 5-repetition maximum during an overhead arm raise in the prone position. The overhead arm raise used in their study, a traditional MMT position for the lower trapezius, included testing the arm in line with the fibers of the lower trapezius, a position that is similar to D2F in that the end position includes shoulder flexion, abduction, and external rotation. Ekstrom et al found %MVC values during their tested movement at 79%, 101%, 97% and 43% for the upper trapezius, middle trapezius, lower trapezius and serratus anterior respectively. These values are considerably higher than the measurements in the current study but are likely explained by changes in the amount of resistance. The three pound weight used in the current study would not have approached the five repetition maximum in the study by Ekstrom and associates. In addition, the variation in the positioning of the body may account for differences in reported %MVC. The values reported by Ekstrom and associates were obtained in a prone position while the current study was performed with subjects in a sitting position. The effects of gravity on the arm could have altered the activation patterns of the scapular muscles contributing to the lack of consensus between the two studies.

While a true D1F pattern has not been investigated in other studies to the authors’ knowledge, Ekstrom et al studied upper and lower serratus anterior EMG activity as maximal manual resistance was applied in a position of shoulder flexion, horizontal adduction and external rotation. A %MVC of 66% for the upper serratus anterior and a %MVC of 73% for the lower serratus anterior were reported for this static position. This position is similar to the end position of the D1F pattern which, in the current study, resulted in a mean %MVC of 50% for the serratus anterior (not assessed as upper or lower portions). Variations in EMG placement could explain the differences in activity as well as differences in the amount of pressure and the performance of a maximal end range contraction versus a dynamic contraction.26

**Application to clinical practice**
While some discrepancies with previous literature are noted due to varying position and resistance, the results of this study can assist in the selection of diagonal patterns that maximize or minimize EMG activity.

The D2 flexion pattern with elastic resistance consistently activated all of the scapular muscles at levels that were 40% of the MVC. In addition, because D2 flexion with a weight was not significantly different from D2 flexion with elastic resistance, it could be utilized to achieve similar levels of muscular activity regardless of type of resistance. While activation of all scapular muscles may be desired, in some clinical conditions, inhibition of the upper trapezius may be recommended to avoid excessive scapular elevation during overhead movements.27,28 If the goal is to mini-
mize upper trapezius activity, while eliciting activation of the remaining scapular muscles, the use of D2 extension with elastic resistance may be the preferred clinical choice. The D2 extension with elastic resistance yields among the lowest upper trapezius %MVC output yet is accompanied by serratus anterior activity that is comparable to all of the other patterns. In addition, D2 extension using elastic resistance as performed in the current study resulted in the third highest %MVC for the middle trapezius and lower trapezius.

Interestingly, the patterns of activation of all three trapezius muscles between patterns and between types of resistance were remarkably similar (see Figure 7). The upper, middle and lower trapezius exhibited consistently higher %MVC output during the D2 flexion pattern with either elastic resistance or a weight, intermediate output during the D1 flexion pattern with either elastic resistance or a weight and the lowest level output during the D1 and D2 extension patterns. This is in contrast to the serratus anterior, where similar %MVC output values were produced regardless of pattern or resistance. Selection of a pattern to activate the serratus anterior may be guided by the need to maximize or to minimize activity of the remaining scapular muscles. For the clinician seeking to isolate the serratus anterior, the results of this study suggest that a D1 extension pattern with elastic resistance would provide equal %MVC to the D1 flexion pattern but without the higher levels of trapezius activity.

Limitations
The data collected in this study is limited by the population studied, the use of surface EMG as a measurement of muscle activity and the type of resistance used. The population included healthy subjects with no attempt to determine the influence of regular exercise, past sports related activities, or current fitness levels. However, muscle activity was compared as a % of an individuals' MVC which can compensate for differences in baseline strength and capacity.

The selection of the amount of resistance in this study may have also influenced the results. Clearly, a three pound weight would not be a maximal amount of isotonic resistance for all of the subjects nor would blue elastic resistance be maximal elastic resistance. However, the amount of resistance used likely falls within the ranges of resistance utilized during rehabilitation of individuals with scapular and shoulder dysfunction. Future studies could standardize this amount by using a dynamometer to objectively determine the force production of the muscles of each subject, and then incorporate a calculated isotonic resistance during performance of the movements being studied. Some variation, even with this alternative methodology, would be expected as diagonal patterns are three dimensional and consistent resistance in all three planes would be questionable. The submaximal amount of resistance in this study may have been adequate in identifying contraction patterns and to be used in support of exercise selection.

In regards to the use of surface EMG to measure muscle activity, this methodology certainly exposes data collection to the possibility of cross talk between muscles. However, the use of EMG to record superficial muscles is well accepted and common in rehabilitative research.

CONCLUSIONS
This study supports the use of a D2 flexion pattern with elastic resistance or with a weight to achieve the greatest activation of the upper trapezius, middle trapezius, lower trapezius and serratus anterior muscles. If minimization of upper trapezius activity with maximization of the lower trapezius and serratus anterior is desired, a D2 extension pattern with elastic resistance is recommended. Isolated activation of the serratus anterior with minimization of activation of all parts of the trapezius muscle occurred during D1 extension with elastic resistance.

REFERENCES


ABSTRACT

Introduction: A tear of the anterior cruciate ligament (ACL) represents a significant injury for an athlete that requires substantial time away from sport, and significant rehabilitation after reconstruction. The physical therapist is responsible to determine when a patient is capable of tolerating the physical demands of daily activities and to attempt to prevent re-injury. Physical or functional performance tests (FPTs) are one mechanism used to evaluate the athlete’s physical skills and capabilities prior to returning to sports participation. The purpose of this systematic review is to critically examine the clinical utility of functional performance tests used with patients less than or equal to one year post ACL reconstruction.

Methods: A systematic review of the relevant literature was performed using PRISMA guidelines. A total of twelve studies were included for analysis.

Results: Two independent blinded reviewers then analyzed and rated the final included articles (n=12) utilizing the Newcastle-Ottawa Scale (NOS). Percent overall agreement between raters for the NOS was 88% with a fixed marginal kappa (κ) of 0.80. Of the 12 included articles, the FPTs were utilized as an outcome measure within the study design (41.7%) or studied as a measure of function (58.3%). Among those studies that used FPTs as a “measure of function” 71.4% studied a battery of FPTs, while 28.6% studied a single test. None of the studies utilized FPTs as a measure to determine readiness to return to sport.

Discussion: FPTs are being utilized with patients, less than or equal to one year post ACL reconstruction, either as an assessment of functional performance or as an outcome measure. No studies identified a FPT or test battery that has construct or predictive validity for “return to sport” in athletic population one-year post-ACL reconstruction. The identification of the critical elements within the return to sport construct may allow lower extremity performance tests to be developed or test batteries assembled to incorporate the appropriate tests to examine all of these elements deemed critical. Additionally the current FPTs should undergo content and predictive validation to assist the sports physical therapist in determining the readiness of the athlete for return to sport.

Key Words: ACL reconstruction, athlete, physical performance measure
INTRODUCTION

A tear of the anterior cruciate ligament (ACL) represents a significant injury for an athlete that requires substantial time away from sport. The injury requires significant rehabilitation, creates anxiety for an athlete regarding the potential for return to sport at the previous competitive level, and often requires surgical intervention.1-3 Between 43% and 92% of athletes return to sports after ACL reconstruction and an extended rehabilitation intervention (6 to 12 months).4 In clinical practice, it is often the responsibility of the physical therapist to determine when a patient is capable of tolerating the physical demands of daily activities or sports participation, and to prevent reinjury after proper care.5

Determining an individual’s ability to participate in sporting events requires careful evaluation of the rigors and demands on the athlete within his/her designated sport.6 One mechanism used to evaluate an athlete’s ability to safely return to sport post ACL reconstruction is the use of physical or functional performance tests (FPTs). FPTs are designed to evaluate a variety of skills that are necessary to participate in higher level functions such as sport or recreation.6 Functional performance testing requires the ability to move through up to three planes of movement. FPTs are assessed by means of qualitative and quantitative information related to specialized motions involved in functional activities.6 The tests are often utilized for assessment of the athletes’ pain, muscle strength and power, lower extremity joint stability in multiple planes of movement, endurance, muscle flexibility, balance, proprioception, speed, agility, and level of aerobic and anaerobic condition.6,9

Some of the identified FPTs pertaining to the knee following ACL injury and reconstruction include the single-leg hop test, the single leg squat, the active straight leg raise, the in-line lunge, and the deep squat.5,10 Others, such as the shuttle run, side-step10, resisted knee extension, resisted knee flexion, and leg press11, may be used in combination as a test battery to include a variety of constructs that when combined resemble function.

There are numerous FPTs used in the rehabilitation of athletes who suffer a lower extremity injury, such as an ACL reconstruction. The authors are unaware of a comprehensive review of the literature that has examined utility of the FPTs in clinical practice. The authors anticipate that the FPTs are being used clinically as outcome measures to evaluate recovery, to define recovery in terms of function, and to determine if a patient is able to return to sport. Therefore, the purpose of this systematic review is to critically examine the clinical utility of functional performance tests used with patients less than or equal to one year post ACL reconstruction.

Methods

Literature Search

This study was a descriptive systematic review that utilized the PRISMA guidelines12 during the literature search and final reporting phases of the systematic review process. Two authors (EN and AW) independently reviewed titles, abstracts, and keywords of retrieved publications to assess their eligibility. Inclusion criteria were established prior to initiating the search. Articles were included if they were written in English, written within the last two decades (1991-2011), case controlled, randomized control trials, or cohort studies, subjects who were post ACL-reconstruction within one year4, and must have at least one lower extremity/knee functional performance test as the primary measure of the article. Articles were excluded from the review for the following reasons, the study was conducted on healthy subjects, patients over 1 year post reconstruction, if the functional performance measure was used as an intervention and not assessment, and/or if the study population had an ACL deficient knee. The time frame of 12 months was chosen secondary to a study that determined that athletes, on average, met return to sport criteria 6-12 months after surgery.5

The computer-based search utilized was completed on MEDLINE (MeSH terms), PubMed (keywords), along with a multi database search of CINAHL, MEDLINE, HealthSource, and SPORTDiscus. A cross-reference search of key terms was also performed in order to find research evaluating FPTs of the knee for return to sport in a post-operative ACL reconstructed patient population. A MeSH search was conducted using the terms “knee” AND “athletic injuries” OR “athletic performance” AND “sports” AND “exercise test/instrumentation” OR “exercise test/methods.” The keyword search was also performed on PubMed.
utilizing the key terms “anterior cruciate ligament” AND surgery AND injury AND physical performance measures and “lunge” OR “hop test.” To ensure a detailed and comprehensive search strategy, the authors also performed an additional search within academic textbooks and chapters that contained an extensive review of functional performance tests.6

Two authors independently reviewed each study to determine inclusion. Two reviewers independently assessed the methodological quality of all the included studies and recorded their findings.

Newcastle Ottawa Quality Assessment Scale
The ability to assess the quality of study is a critical component of any systematic review. Unfortunately, there were no randomized controlled trials or clinical trials that met the inclusion criteria, which eliminated many validated literature assessment tools. The study designs of case-control and single cohort research designs are appropriate for the population being investigated in this study; therefore appropriately assessing that type of research design becomes important. The NewCastle-Ottawa Scale (NOS) provides an objective assessment of the quality of the type of studies that are included in the current descriptive systematic review.

Wells et al14 proposed a scale for assessing the quality of published non-randomized studies called the Newcastle-Ottawa Scale (NOS). This tool can either be used as a checklist or scale. The NOS was developed using a Delphi process and thereafter was tested on systematic reviews and further refined. Separate NOS scales were developed for cohort and case-control studies. The NOS contains eight items, categorized into three dimensions including selection, comparability, and—depending on the study type—outcome (cohort studies) or exposure (case-control studies). For each item a series of response options is provided. A star system is used to allow a semi-quantitative assessment of study quality, such that the highest quality studies are awarded a maximum of one star for each item with the exception of the item related to comparability that allows the assignment of two stars. The NOS applies to and separately assesses cohort and case-control study designs, whereas other assessment tools do not separate the assessment of these designs.14

Results

PRISMA
A literature search utilizing the PRISMA guidelines yielded a total of 272 articles. After 10 duplicates were removed, a total of 242 were immediately excluded based on title or abstract revealing a lack of relevance to subject matter, non-English language, or that they met exclusion criteria (article included only healthy subjects, the subjects were greater than one-year post-operation, the FPT was used only as an intervention, and/or the ACL deficiency meaning ligament laxity only). A full text review was conducted on 30 articles. A total of eighteen of the 30 full text studies were excluded. Six of the studies were excluded secondary to the studies utilization of subjects that were ACL deficient and not ACL reconstructed,9,15-19 8 studies were excluded based on the incorporation of subjects that were greater than one-year post-ACL reconstruction,7,20-26 and 4 studies were excluded for using healthy subjects only.29-32 A total of 12 studies met the inclusion criteria and were assessed for quality using the NOS.

Inter-rater reliability
The kappa (κ) statistic was used to determine the agreement between raters throughout the PRISMA process. Two independent reviewers then examined the all of the articles during the screening process to identify articles meeting the inclusion and exclusion criteria and to remove duplicates. Agreement was 100% kappa (κ = 1) for the full text articles that were included for evaluation.33

The 12 included studies were evaluated based on study design (Appendix 1). There were no randomized clinical trial studies that met the inclusion criteria. There were only cohort and case series studies included for review. The method of critical article appraisal was completed using the NOS. Two independent blinded reviewers assessed the quality of the 12 included studies utilizing the NOS scoring guide for case control (Table 1) and cohort studies (Table 2). The percent overall agreement between raters based on the total summary score of each article on the NOS was 88%, with a fixed-marginal kappa (κ) of 0.80.34 This implies that the raters demonstrated substantial to almost perfect agreement in their ability to rate the included studies with this tool.33,34
After careful synthesis of each included article, it became apparent that FPTs were utilized as outcome measures within the study design for data collection, and as a measure of function. None of the articles utilized FPTs for determination of return to sport. Table 3 identifies the specific performance test from each study, establishes how tests were utilized, and gives a brief description of each study. Some studies use the FPT for more than one purpose. A majority of the included studies utilized the PPTs as a measurement of function (n=7; 58.3%). Fewer studies utilized the FPT as an outcome measure within the study design (n=5; 41.7%). There were no studies that evaluated return to sport.

The 7 articles that fell within the category ‘assessment of construct validity as a measure of function’ utilized FPTs as a single test or within a battery. The majority of articles were identified as using FPTs as a measure of function within a battery (n=5; 71.4%), while fewer used a single test (n=2; 28.6%) and are identified in Table 4.
DISCUSSION
The purpose of this systematic review is to critically examine the clinical utility of functional performance tests used with patients less than or equal to one year post ACL reconstruction. Of the included articles, seven assessed the construct validity of FPTs as a measure of function. These articles looked at FPTs, whether alone or in a cluster, in terms of development, responsiveness, reliability, and overall validity in different patient populations following ACL-reconstruction. In evaluating the construct of the FPTs, the tests mentioned in Table 3 appear to be well validated in terms of assessing function for return to everyday life, and measuring general functional ability. For example, the single leg hop test and was the most commonly encountered FPT within these studies, alone or clustered with other FPTs. The single leg hop test, which measures maximal distance scored for each limb, is often clustered with double leg hop test, jogging straight forward, cross over hop test, and double legged squat test.

In practice, several FPTs are often grouped into test batteries that are used and supported in the literature to measure power, speed, balance, and single lower extremity control of the athlete. However, there are other measures, such as the Tests for Athlete’s with Knee Injuries (TAK), which demonstrate a more detailed assessment of functional performance. The TAK is a battery of 8 tests that measures strength,
stability, pain, endurance, coordination, active range of motion, and balance.\textsuperscript{10,36} The TAK incorporates many of the necessary components of FPTs, and may arguably have components that may be used for assessing readiness to return to sport. However the TAK has not been studied to ensure validation of content or whether its outcomes can predict ability to return to sport. The authors were unable to find studies that examined the clinical utility of FTP tests or test batteries ability to successfully or unsuccessfully predict return of the athlete to sports beyond the rehabilitative period.\textsuperscript{8} Specifically, the battery or test do not measure an athlete’s performance of the previously mentioned variables necessary to ensure a safe, injury free return to sport.

No studies found to meet the inclusion criteria for this systematic review discussed functional performance tests or battery to examine all of the concepts related to return to sport. It may be clinically important to have physical performance tests that have been validated with in the return to sport construct, which may differ between varied sports. Clinically it may help the practitioner decide which test or test battery to use for assessment and assist in the decision making when returning an athlete back to a high demand sport. The current lack of literature to guide clinical decisions may suggest that clinicians rely on their intuition or clinical experience when making this determination.

The remaining five\textsuperscript{3,37-40} articles utilized FPTs an outcome measure within the respective study design. This allowed the authors to determine the effectiveness of the FPT as a means of assessing the athlete's projected results. These studies utilized scores obtained from the hop test to measure biomechanical adaptations in the post-ACL reconstructed patient, and found that compensations by other joints can suggest protective adaptation mechanisms to avoid loading through the reconstructed knee.\textsuperscript{38} A positive correlations has been identified with the three variations of the hop test and knee extension torque. A significant correlation was found between quad strength and functional stability.\textsuperscript{39,40} The single limb hop for distance and the cross-over hop test scores were found to serve as an indicator of an athlete’s likelihood to return to sport.\textsuperscript{37} The single limb hop test as an outcome measure has been validated to measure multiple concepts with in the functional performance testing construct, including strength, stability, and patient subjective report of performance.\textsuperscript{6} Functional performance testing has been used to identify progress, discover weak components in an athletes’ performance, and guide treatment progression in the clinical setting.\textsuperscript{8} Although, functional performance testing is valuable in the assessment of ACL injured patients, this systematic review did not identify any clinical test or battery of tests that predicts the athletes' ability to return to play sports.

Further research is needed to identify what specific components of physical performance are required for an athlete to return to sport after sustaining a lower extremity injury. The identification of the critical elements or components within the return to sport construct may allow lower extremity performance tests or test batteries to be developed to incorporate the appropriate tests to examine all of these elements deemed critical. Future research should be conducted in order to examine the predictive ability of FPTs or whether a given test battery predicts the athletes’ ability to return to play sports. This type of research could aid in the decision making for clinicians when attempting to return an athlete back to sport safely within one-year post ACL reconstruction.

**Limitations**

As previously described, the utilization of the New Castle Ottawa Scale to evaluate studies in this literature review poses a limitation within the study. The NOS is in the developmental phases of defining study quality as poor to good, but was the only scale found to separately assess the included cohort and case-control study designs. However, the use of this scale in the current study may add to the literature that utilizes the NOS for assessment. Recall that minimal variability was found in the authors assessment of the actual quality of articles included in this systematic review with an inter-rater reliability of 88%.

An additional limitation may have been the exclusion of studies that included subjects that had an ACL reconstruction more than one year previously. This may have allowed the authors to miss some additional characteristics of the FPTs used on a population with delayed healing. However, the literature review conducted for this systematic review suggested that many athletes met return to sport criteria on average 6-12 months post-surgery.\textsuperscript{4} While study results have
shown that the typical individual will return to sport within 6-12 months, there is not a definitive objective measure that determines if this time frame is appropriate. Therefore, studies that included subjects greater than one-year post ACL reconstruction may have utilized functional tests in order to determine readiness to return to sport in those athletes. Consequently, a more thorough analysis using those studies that examine athletes greater than one year post-operatively could potentially generate additional results, which may assist a clinician in making a judgment regarding readiness to return to sport.

CONCLUSION

There is a lack of literature that examines the clinical utility of functional performance testing in relationship to return to sport one-year post-ACL reconstruction. The clinical utility of FPTs identified in this review suggests that they are used as a measure of function or as an outcome measure. Based on the authors findings, one isolated functional test may be insufficient to assess the dynamic functional capacity of an athlete required to return to playing sports. A functional performance testing battery may incorporate multiple performance variables (i.e. strength, power, proprioception, balance, endurance, flexibility, speed, agility, aerobic conditioning, and lower extremity joint stability in multiple planes of movement) that more broadly address the necessary sport specific demands. The identification of physical performance measures (i.e. cutting, stability, power, etc.) of the lower extremity for the athlete to successfully return to sport is needed may be needed. This may allow additional performance tests to be developed or test batteries developed to incorporate the appropriate tests to examine all of these elements deemed critical. Additional validation studies in this area should be performed in order to guide a safe return to sport following an ACL re-injury in the first year following reconstruction.

REFERENCES


# APPENDIX: DESCRIPTIONS OF THE 12 INCLUDED STUDIES.

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<td>Wilk et al 1994⁴⁰</td>
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<td>Paterno et al 1996⁴²</td>
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<td>Neeter et al 1996⁴¹</td>
<td>N=13 subjects with no history of lower extremity injury; N=23 subjects with 6 months post ACL injury; N=24 subjects 6 months post ACL reconstruction</td>
<td>Development of a test battery of lower extremity strength tests with high ability to discriminate between leg power development</td>
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<td>Colby et al 1999⁴³</td>
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<td>Gustavsson et al 2006⁴⁶</td>
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<td>Bjorkland et al 2009&lt;sup&gt;10&lt;/sup&gt;</td>
<td>N=35 subjects tested 4 and then 8 months post ACL reconstruction</td>
<td>Evaluation the validity and responsiveness of the ‘Tests for Athletes with Knee Injuries’</td>
<td>Jogging straight forward 2 x 20 m and then in a figure of eight; Fast running straightforward 2 x 20 m with acceleration to full speed; one-leg standing flexing the knee x 3; Rising on one leg from a seated position with the knee flexed in 90° x 3; squatting down with equal weight on both legs x 3; One-leg hop for distance; 10 hops in rapid succession hopping as far distance as possible; One-leg vertical jump in rapid succession: jumping as high as possible, using the stretch shortening cycle x 5; crossover one-leg hops in rapid succession.</td>
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<td>Orishimo et al 2010&lt;sup&gt;18&lt;/sup&gt;</td>
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<td>Reid et al 2007&lt;sup&gt;15&lt;/sup&gt;</td>
<td>N=42 subjects testes 16 weeks and 22 weeks post ACL reconstruction</td>
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<td>Keays et al 2003&lt;sup&gt;19&lt;/sup&gt;</td>
<td>N=31 subjects tested 1 week pre- and 6 months post ACL reconstruction</td>
<td>Assessment of the relationship between muscle strength and functional stability in pre- and post-operative ACL reconstructed knees</td>
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<td>Lentz et al 2009&lt;sup&gt;3&lt;/sup&gt;</td>
<td>N=58 subjects 6-12 months post ACL reconstruction</td>
<td>Investigation of the association of knee impairment and psychological variables with function in subjects with ACL reconstruction</td>
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<tr>
<td>Ardern et al 2011&lt;sup&gt;17&lt;/sup&gt;</td>
<td>N=503 post-ACL reconstructed athletes</td>
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<td>Single hop for distance; triple cross over hop</td>
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ABSTRACT

**Background and Purpose:** Golf is a popular sport played by hundreds of thousands of individuals of all ages and of varying skill levels. An orthopedic or sports-related injury and/or surgery may limit an individual's sport participation, require him/her to complete a course of rehabilitation, and initiate (or resume) a sport-specific training program. Unlike the availability of evidence to guide postsurgical rehabilitation and sport-specific training of athletes from sports other than golf, there have only been two reports describing outcomes after surgery and for golfers. The purpose of this case report is to present a post-rehabilitation return to sport-training program for a recreational golfer 11-months after a rotator cuff repair.

**Case Description:** The subject, a 67-year old female, injured her right shoulder requiring a rotator cuff repair 11-months prior to her participation in a golf fitness training program. The subject participated in six training sessions over seven week period consisting of general strengthening exercises (including exercises for the rotator cuff), exercises for the core, plyometrics, and power exercises.

**Outcomes:** The subject made improvements in power and muscular endurance of the core. She was able to resume golf at the completion of the training program.

**Discussion:** The subject was able to make functional improvements and return to golf after participation in a comprehensive strength program. Additional studies are necessary to improve program design for golfers who wish to return to sport after shoulder surgery.

**Key Words:** golf, return-to-sport, senior, kettlebells, plyometrics
BACKGROUND AND PURPOSE
Golf is a popular sport played by hundreds of thousands of individuals of all ages and of varying skill levels. Despite the low-impact nature of the sport, golfers are at risk for injury. Sport-related golf injuries have been reported in the lower back, elbow, shoulder, and knee. Potential risk-factors for a golf-related injury include a lack of warm-up, poor trunk flexibility and strength, faulty swing technique, and overuse.

A musculoskeletal injury may impair an individual's ability to play golf. The golfer who is sidelined by an injury may experience decrements in performance due to lost practice time and a decrease in fitness. Case reports and clinical commentaries have provided treatment suggestions to guide the rehabilitation management for the injured golfer. These clinical recommendations include the prescription of endurance and strength training exercises, flexibility exercises, and plyometrics. In addition, many golfers may benefit from swing analysis and instruction from a golf professional. Improving swing mechanics may reduce risk for a sport-related injury; however, there is no prospective evidence to support this claim.

An orthopedic injury and/or surgery may also limit sport participation and require the golfer to complete a lengthy course of rehabilitation. However, unlike the availability of evidence to guide postsurgical management and return to sport strength training programs for athletes who perform sports other than golf, there are only a few reports describing outcomes after surgery for golfers. Jackson et al reported that a total knee arthroplasty may relieve pain in golfers with degenerative joint disease and the majority of their subjects reported playing golf as much or more post-operatively than pre-operatively, and with less pain (81% and 83% respectively). A majority of patients returned to golf 4 to 6 months after surgery (13% returned after 0-3 months, 44% after 4-6 months, 43% 7 months or later). Jensen et al reported that a majority of patients (23 out of 24) were able to return to golf after either a shoulder arthroplasty or hemiarthroplasty. Physician members of the American Shoulder and Elbow Society suggest that the mean time for one to return to sport after a shoulder arthroplasty is 4.3 months (range 2-12 months).

Despite the published clinical rehabilitation recommendations and a few reports that demonstrate successful return to sport after surgery, there is a paucity of literature regarding golf specific rehabilitation or post-rehabilitation return to sport training programs. The purpose of this case report is to describe a post-rehabilitation return to sport training program for a recreational golfer with a recent rotator cuff repair.

CASE DESCRIPTION: PATIENT HISTORY AND SYSTEMS REVIEW
The subject, a 67-year old female (right hand dominant, height 1.59 m, 87.54 kg, BMI = 34.7), injured her right shoulder 11-months prior to her participation in a golf fitness training program. Her injury was the result of a trip and fall. Symptom onset including pain, loss of function, and swelling, was immediate. A computerized tomography (CT) scan revealed a comminuted fracture of the right scapula involving the both the superior and inferior aspects of the glenoid with the inferior fracture extending into the anterior body of the scapula. The fracture was considered stable by her orthopedic physician; she was immobilized with a sling, and referred to the orthopedic physician group's physical therapy practice for passive and active-assisted range of motion exercises. At her next physician appointment she reported an inability to actively elevate her arm despite good healing of the fracture site. A subsequent MRI arthrogram revealed a full-thickness rotator cuff tear with a supraspinatus defect and degeneration of the long head of the biceps tendon. Two months after her injury a mini-open rotator cuff repair and biceps tenodesis was performed. It should be noted that the immediate postoperative physical therapy for this patient was not provided by the authors of this case report. She began physical therapy 5 weeks after surgery. At the 3 month follow up with her orthopedic physician she demonstrated full flexion and abduction, 60° degrees of shoulder external rotation, 5/5 strength (traditional manual muscle testing positions) of the supraspinatus and shoulder internal rotators, and 4/5 strength of shoulder external rotators as reported in the physician's chart notes. She was formally discharged 7-months post-operatively with no activity restrictions, the length and details of supervised physical therapy were not reported by the treating therapists.
Clinical Impression #1
The subject, 11-months post-surgery, self-referred to a golf-fitness research study (responding to an advertisement in a local newspaper). The research study was approved by the Pacific University Institutional Review Board. The subject was informed and she approved that the data collected and presented in this case would be submitted for publication.

Prior to participating in the golf-fitness training program, each subject had to read and sign the informed consent form and complete the Physical Activity Readiness Questionnaire (PAR-Q). The PAR-Q is a 7-question form for individuals aged 15 to 69 years, to be completed prior to increasing physical activity. The PAR-Q is designed to identify individuals who require assessment by their primary provider prior to initiating or increasing a training program. The PAR-Q screens for the following conditions/situations: heart conditions requiring physician supervision, chest pain during activity, chest pain unrelated to activity level during the previous 30 days, orthopedic conditions that may worsen after activity, medications for hypertension or heart conditions, and any other condition that should prevent one from exercise. The subject answered “no” to each of the 7 questions allowing her to begin the program without physician approval.

The subject was appropriate to initiate a golf fitness exercise program based on her physician’s discharge recommendations and her score on the PAR-Q. To meet her goal of returning to golf, a progressive, functional exercise program might prepare her for the biomechanical stresses applied to the body during the golf swing and could potentially impact her golf performance variables (e.g. club head speed, driving distance). Addressing any muscular imbalances, general muscular weakness, or deficits in flexibility may help to reduce the risk of reinjury or subsequent injury to another region of the body. Although the subject was cleared to return to all activities by her physician, assessment of her shoulder function was warranted. It is not uncommon for some subjects to experience some muscular weakness or limitations in range of motion, even after a successful rotator cuff repair.

Examination
Baseline tests and measures were recorded before the start of the 1st training session. Muscular endurance, strength, and power tests were performed to assess functional abilities related to readiness for sport and the strength of the postoperative shoulder. These tests were administered as part of a larger study assessing the effect of a golf specific training program on sport performance and fitness. Range of motion testing of the shoulders was performed to identify any asymmetries that might exist on the postoperative side. These tests were performed specific to this subject due to her history of rotator cuff repair.

The selection of exercises for the golf training program was twofold: to train functional aspects of the golf swing and to minimize risk of injury. As previously mentioned, golfers are at risk for injury to multiple regions of the body. The functional tests that were administered were chosen for their ability to identify upper extremity power and core muscular endurance. The number one injury region for both amateur and professional golfers is the spine. During the swing the lumbar spine experiences compression, shearing, rotation, and lateral bending forces. Muscular endurance tests for the core were performed, including the prone bridge (Figure 1), the back extensor test (Figure 2), and flexor endurance test (Figure 3). Details regarding the performance of each assessment can be found in Table 2. Results of these functional tests (Table 1) revealed both asymmetry and limited endurance capacity. Ratios between muscular endurance tests (back extensor, flexor endurance, and the lateral musculature tests) are reported to assess muscular endurance capacity and their potential risk for a musculoskeletal injury in the core region. Risk of low back injury is increased in...
individuals with limited muscular endurance of the core. The following ratios between tests are suggested to demonstrate muscular endurance of the core and balance between the muscle groups: flexion/back extensor < 1; left/right lateral musculature ratio < 0.05 difference; and lateral musculature (either side)/back extensor ratio < 0.75. As can be observed in Table 1, the patient’s ratios for each comparison failed to meet the standards.

Upper extremity strength was assessed by traditional manual muscle tests. Her bilateral shoulder strength was graded as 4+ / 5 or greater (bilateral external rotation weakest group at 4+/5). Upper extremity power was assessed by performing the seated chest pass (Figure 4). Refer to Table 2 for description of the performance of this functional test. The seated chest pass was selected as a general upper extremity power test because most active individuals can assume the testing position and the test does not require a large testing area. Mean passive range of motion (goniometry) measures were 110° of external rotation and 61° of internal rotation on the left (left total arc of rotation motion = 171°) and 92° of external rotation and 65° of internal rotation on the right (right total arc of rotation motion = 157°). The purpose of assessing

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<td>1.8 kg ball (mean distance)</td>
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<td>3.2 kg ball (mean distance)</td>
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*Modified lateral musculature test position (subject weightbearing on knee closest to mat instead of on the feet).
passive range of motion was to identify if any residual deficits existed. Because of the client's post-surgical status, the Constant-Murley Shoulder Outcome Assessment was administered. Diercks et al report that a score of at least 80 is a clinically significant measure that would identify an individual as having a functional, healthy shoulder. The patient scored 78, indicating mild shoulder dysfunction, which would be appropriate for ongoing intervention. The primary purpose of administering the Constant-Murley Shoulder Outcome Score at that start of the training program was to assess if there was a particular domain of shoulder health (range of motion, activity level, pain, strength) that was limited. The outcome tool was not

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<td>Subject assumes a prone bridge (also described as a prone plank) position. Record how long individual is able to maintain this position.</td>
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<td>Back Extensor Test</td>
<td>Subject assumes a prone position with torso positioned off the end of the table. Therapist supports the lower extremities by either manually stabilizing the legs with one's body weight or, if available, use a strap to stabilize the client’s lower body. Record how long the individual is able to maintain her torso in a neutral position. Stop the test if the patient fatigues or if one starts to compensate by hyperextending at the low back.</td>
<td>Figure 2</td>
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<tr>
<td>Flexor Endurance Test</td>
<td>Subject is positioned with back resting against a jig or a bolster (angled approximately 60°). Hips and knees are flexed to 90°. The back support is slid 10 cm away from the subject. Therapist provides stabilization force at ankles. Record how long the position can be held. Test is stopped with loss of posture (back coming in contact with bolster).</td>
<td>Figure 3</td>
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<tr>
<td>Lateral Musculature Test</td>
<td>Subject assumes a side bridge position (also described as a side plank). Record how long one can maintain this posture. For this case the subject was allowed to weight-bear through her knees instead of her feet (modified test position).</td>
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<tr>
<td>Seated Chest Pass</td>
<td>Subject assumes a long sitting position with back, head, and shoulders against a wall. Ball is held in front of the body at the chest. Subject performs a two-armed chest pass with the goal of throwing the ball as far as possible.</td>
<td>Figure 4</td>
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</table>
Clinical Impression #2
The subject presented with bilateral shoulder weakness and muscular weakness of the core. We hypothesized at the end of the 8-week training program (60-minute supervised training session performed once a week) the subject would demonstrate improvements in muscular core endurance, upper extremity power, and would be able to return to sport participation.

INTERVENTION
The training program consisted of exercises to increase strength of the shoulder and legs, exercises to improve muscular endurance of the core, and exercises to enhance power (Table 3). All exercises used with this subject are described in the Appendix. The subject was instructed to walk briskly daily for aerobic exercise as time available in the clinic did not allow for aerobic exercise. Exercise performance was evaluated after each training session by reviewing of the number of reps and sets that was performed. Recommendations to increase or decrease training load (weight) was made based the ability to complete training volume.

Core Training
The “core” is the region of the body consisting of the joints and muscles of the lumbar spine, the pelvis, and the hips.4,28 As previously mentioned, the lumbar spine is susceptible to golf-related injuries.4,23 During baseline testing the client demonstrated both limited muscular endurance capacity of the core and muscular imbalance (as indicated by ratio scores between tests presented in Table 1). Initial core exercise prescription consisted of mat/table exercises such as the prone and side plank, with the goal of increasing muscular endurance. The vertical swing described in the Appendix (Figure 5) was also initiated during the first training session. The vertical swing is a functional core training exercise mimicking the diagonal movement patterns associated with the golf swing.11,28 As her core muscular endurance capacity improved the client was progressed from basic (e.g. bridging) and intermediate intensity (e.g. Russian Twist) (Figure 6) core exercises to functional strengthening and power exercises that incorporated activation of the trunk.28

Legs and Shoulders
Squats were performed to increase lower extremity functional strength. Dumbbells were held in each hand to increase the challenge once the client was able to perform the initial desired number of sets and reps. The static single leg balance exercise (with eyes open) was performed during each training session. A golfer must be able to weight shift between bilateral stance and single leg stance during the golf swing. Improving one’s ability to balance on one extremity may help to improve control during the swing.29

The muscles of the shoulder girdle are active throughout the golf swing.30,31 Strengthening the muscles of the rotator cuff and the scapular stabilizers may help improve performance and may reduce risk of shoulder injury.2,6,30,31 In this case, training the shoulders was potentially beneficial to address postoperative weakness. To improve muscular

Figure 4. Seated chest pass (test for UE power).
endurance of the scapular stabilizers and the rotator cuff, 15 repetitions were performed in each set of each exercise. (Figures 7,8,9)

**Power and Plyometric Exercises**

The golf swing is considered a power movement. Meira and Brumitt suggest that golfers may benefit from golf-specific plyometric exercises (exercises designed to improve power utilizing the stretch-shortening cycle) for the trunk and the use of Olympic lifts. Performing Olympic lifts (e.g. clean, push jerk) may help to develop the explosiveness necessary to maximize clubhead speed. Because of the age and fitness status of this client, careful consideration went into the prescription of power and plyometric exercises. Plyoball throws to a rebounder were the first plyometric exercise chosen to increase power. (Figures 10 and 11) These low intensity exercises were progressed as tolerated to exercises of greater intensity such as medicine ball (Figures 12, 13, and 14) and kettlebell swing exercises (Figures 15 and 16). The medicine ball exercises were performed to improve functional power (utilizing rotation and diagonal patterns) and to strengthen muscles of the core and the upper extremities. The use of Olympic lifts was considered inappropriate for this subject because performing a traditional Olympic lift using only the barbell would have been too heavy; however, the use of kettlebell exercises was included to enhance power development. The shape of the kettlebell and its handle allow an individual to swing the weight through a curvilinear arc of motion (Described in Appendix).

**Outcomes**

At the completion of the training program tests for muscular endurance capacity and power were
repeated (Refer to Table 1). Her muscular endurance capacity improved in some of the test positions (back extensor test, flexor endurance, and (R) lateral musculature endurance) as did some of the ratios between tests. The mean distance of each seated chest pass (1.8 kg & 3.2 kg) also increased.

In addition to the aforementioned tests, a computerized analysis of the subject’s golf swing was performed.
at the end of the training program. Up to this point, the client had yet to practice swinging her clubs. The P3ProSwing Virtual Golf Simulator and Golf Swing Analyzer (Sports Vision Technologies, Bethlel, ME) provides data related to (but not limited to) driving distance, club speed, ball speed, and swing tempo. The client performed 5 swings each with her favorite wood and iron. Data related to those swings is presented in Table 4. Means (±SD) were calculated for golf performance scores. SPSS 17.0 (Chicago, IL) was used for the statistical analysis. The subject reported to the lead author that she had returned to golf for the first time since injuring her shoulder a week after the last golf fitness training session.

**DISCUSSION**

The purpose of this case report is to describe a post-rehabilitation return-to-golf fitness program for a 67-year old female who was 11-months post rotator cuff repair. The aforementioned training program addressed both the client’s fitness limitations and functional aspects of the sport previously described by other authors. At the end of the training program the client was able to demonstrate some improvements in muscular endurance and power and was able to return to sport.

Despite the positive outcomes described for the subject in this case, there are limitations to this case report and generalizations or blanket recommendations cannot be made. Other training components and varied exercise prescription should be considered in the future. Meira and Brumitt suggest that a comprehensive training program should include flexibility exercises, strength training, core training, and power exercises. The program described in this case report contained 3 of the 4; however, specific flexibility exercises were not addressed. Prior to the start of each training session, the subject performed a dynamic warm-up; however, it was probably not a sufficient strategy to address all regions of muscular inflexibility. Due to the limited time frame of the training program in the larger research study (conducted over an 8-week period) and the subject’s ability to only meet once a week, flexibility exercises were not prescribed.
Figure 12. Medicine ball side-side rotations, performed with a partner.

Figure 13. Medicine ball side-side rotation with diagonal component, performed with a partner.

Figure 14. Sit-up with ball toss.

Figure 15. 1 Arm kettlebell swing, a) beginning position, b) end position.

Another aspect of conditioning that the authors did not test or control for was aerobic fitness training. Again, due to the limited time spent with the subject
in the clinic, appropriate time could not be devoted in order to meet the minimum aerobic fitness exercise guidelines recommended by the Centers for Disease Control (a minimum of 150 minutes of moderate aerobic exercise per week). The subject was instructed to independently perform aerobic exercises (e.g., walking briskly) as previously mentioned.

Finally, if time had permitted, the authors would have performed additional functional tests and/or used dynamometry to objectively assess strength and power. Due to the individual’s age and fitness level there are limited types of lower extremity strength and power tests that could be performed (due to safety considerations and complexity of the movements). The utilization of a hand-held dynamometer would have improved the quantification of the client’s shoulder girdle strength both at baseline at the end of training period.

To the authors’ knowledge, this is the first case report to describe a return to golf fitness training program in a senior-aged, recreational golfer who was post-rotator cuff repair. The training program performed addressed her functional weaknesses and demonstrated positive outcomes for aspects of muscular endurance and strength. The client was able to return to golf and was provided with a home training program that included many of the program’s exercises. Aspects of this program may be useful to other rehabilitation professionals when prescribing a functional golf-specific program for a similar client.

### Table 4. Golf Performance Measures with Subject’s Favorite Wood and Iron.

<table>
<thead>
<tr>
<th>Club</th>
<th>Hit Distance (m)</th>
<th>Club Speed Entry (mph)</th>
<th>Club Speed Exit (mph)</th>
<th>Ball Speed (mph)</th>
<th>Swing Tempo (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Wood</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swing #1</td>
<td>148.6</td>
<td>63.6</td>
<td>58.9</td>
<td>94.1</td>
<td>1.3</td>
</tr>
<tr>
<td>Swing #2</td>
<td>132.8</td>
<td>57.2</td>
<td>49.3</td>
<td>84.7</td>
<td>1.2</td>
</tr>
<tr>
<td>Swing #3</td>
<td>122.7</td>
<td>53.1</td>
<td>50.7</td>
<td>78.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Swing #4</td>
<td>121.2</td>
<td>52.4</td>
<td>49.2</td>
<td>77.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Swing #5</td>
<td>129.4</td>
<td>56.0</td>
<td>52.6</td>
<td>82.9</td>
<td>1.4</td>
</tr>
<tr>
<td>Means ± SD</td>
<td>130.9 ± 11</td>
<td>56.5 ± 4.5</td>
<td>52.1 ± 4.0</td>
<td>83.6 ± 6.6</td>
<td>1.3 ± .1</td>
</tr>
<tr>
<td>6-Iron</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swing #1</td>
<td>93.5</td>
<td>48.6</td>
<td>48.0</td>
<td>72.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Swing #2</td>
<td>39.2</td>
<td>34.1</td>
<td>22.9</td>
<td>50.5</td>
<td>1.2</td>
</tr>
<tr>
<td>Swing #3</td>
<td>70.4</td>
<td>37.3</td>
<td>38.0</td>
<td>55.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Swing #4</td>
<td>91.9</td>
<td>50.2</td>
<td>55.1</td>
<td>74.4</td>
<td>1.2</td>
</tr>
<tr>
<td>Swing #5</td>
<td>81.3</td>
<td>42.8</td>
<td>37.5</td>
<td>63.4</td>
<td>1.2</td>
</tr>
<tr>
<td>Means ± SD</td>
<td>75.3 ± 22</td>
<td>42.6 ± 7.0</td>
<td>40.3 ± 12.2</td>
<td>63.1 ± 10.3</td>
<td>1.2</td>
</tr>
</tbody>
</table>
REFERENCES


## APPENDIX: DESCRIPTION OF SELECTED EXERCISES

<table>
<thead>
<tr>
<th>Selected Exercises</th>
<th>Technique Description</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Core</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prone Bridge (aka prone plank)</td>
<td>Subject assumes a plank position supporting the body with the forearms and on the toes. The body should be maintained in neutral alignment (straight). Hold the position as instructed and repeat. Modification: performed with knees supporting body instead of toes.</td>
<td>Refer to Figure 1</td>
</tr>
<tr>
<td>Side Bridge (aka side plank)</td>
<td>Subject begins side-lying with the elbow and forearm positioned under the shoulder. Subject’s feet are either positioned one on top of the other or with one positioned to the front of the other. The plank positioned is held with the head, torso, and legs in alignment. Hold the position as instructed and repeat. Modification: performed with knees flexed, and the closest to mat weight-bearing instead of feet.</td>
<td>No Figure</td>
</tr>
<tr>
<td>Vertical Swing</td>
<td>From a deep squat position, the subject grasps the kettlebell that is placed laterally to one foot. The movement is performed by lifting the kettlebell diagonally from a low to high position. The kettlebell is returned to the start position and repeated. The exercise is performed from each side.</td>
<td>Figure 5</td>
</tr>
<tr>
<td>Russian Twist</td>
<td>The subject positions her back on a physioball with the lower extremities positioned in neutral hip extension, 90° of knee flexion, and the feet positioned flat on the ground. The arms are extended in front of the body with the fingers interlocked (or holding a medicine ball). The individual rotates from one side to the other maintaining torso in neutral alignment.</td>
<td>Figure 6</td>
</tr>
<tr>
<td><strong>Shoulders</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoulder Extension</td>
<td>Subject lies prone with arm hanging off the side of a table and the shoulder externally rotated. The arm is lifted (shoulder extended) in line with the torso.</td>
<td>Figure 7</td>
</tr>
<tr>
<td>Shoulder Row</td>
<td>Subject lies prone with arm handing off the side of a table and the shoulder positioned in a neutral position. The shoulder is extended and the elbow flexed (sawing motion).</td>
<td>Figure 8</td>
</tr>
<tr>
<td>Scaptions</td>
<td>Subject is standing with shoulders externally rotated and arms positioned along one’s sides. The arms are elevated in the plane of the scapula, flexing the shoulders to 90°.</td>
<td>Figure 9</td>
</tr>
</tbody>
</table>
### Plyometric and Power Exercises

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Description</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overhead Throw to Rebounder</td>
<td>The subject stands facing a rebounder with arms holding a plyoball overhead. The ball is thrown to rebounder as many times as possible during a specific period of time.</td>
<td>10</td>
</tr>
<tr>
<td>Side Throw to Rebounder</td>
<td>The subject stands perpendicular to a rebounder throwing the ball across their body as many times as possible during a specific period of time. Side throws are performed to each side of the body.</td>
<td>11</td>
</tr>
<tr>
<td>Medicine Ball Side to Side Rotation</td>
<td>Subject stands back to back with another golfer. Holding a medicine ball, the subject rotates to her left handing the ball to the other person then rotates to her right to receive the ball. This pattern is performed both directions.</td>
<td>12</td>
</tr>
<tr>
<td>Medicine Ball High to Low Rotation</td>
<td>This exercise is performed similar to medicine ball side to side rotation except that the subject rotates the medicine ball across her body handing the ball to her partner at her shoulder and receiving the ball at her hip. This pattern is performed both directions.</td>
<td>13</td>
</tr>
<tr>
<td>Sit-Up with a Toss</td>
<td>Subject is sitting with hips and knees bent and her partner stands approximately 2 to 3 feet away. The partner throws the ball to the sitting subject who catches the ball while lowering her torso to the mat. The subject reverses the position, sitting up and tossing the ball back to the partner.</td>
<td>14</td>
</tr>
<tr>
<td>Kettlebell 1-Arm Swing</td>
<td>Subject starts in a squat position with one arm holding a kettlebell that is situated between the legs with an overhand grip (17a). To initiate the swinging motion, the individual grabs the kettlebell swinging it forcefully to the height of their head (17b). During the descent from the position, the kettlebell is lowered between the legs, slightly posterior to the body. From this position, the swinging motion is repeated; power should be generated by the hips and knees.</td>
<td>15 a,b</td>
</tr>
<tr>
<td>Kettlebell 2-Arm Swing</td>
<td>Performed the same as the 1-arm swing except that both hands are grasping the kettlebell handle. Start position 18a, finish position 18b.</td>
<td>16 a,b</td>
</tr>
</tbody>
</table>
ABSTRACT

Chest injuries in contact and collision sports are relatively rare, particularly those that are life threatening. However, as with every sports related injury, one must initially consider life threatening situations that may occur as a result of collision with another player, a stationary object, or being struck with some type of object (missile). In other words, as is the case in all acute sports injury assessment, the mechanism of injury must be considered when evaluating the injured athlete on the field as well as on the sidelines. The Sports Physical Therapist (PT) must look for several initial life threatening conditions as well as be aware of and monitor for the development of these symptoms during the subsequent evaluation of the athlete. The purpose of this clinical commentary is to review the presentation and management of several emergent conditions associated with injuries to the chest and thorax.

Key Words: Chest injury, commotio cordis, flail chest, pneumothorax
INTRODUCTION

Chest injuries in contact and collision sports are relatively rare, particularly those that are life threatening. However, as with each sports related injury, one must initially consider life threatening situations that may occur as a result of collision with another player, a stationary object, or being struck with some type of object (missile). In other words, as is the case in all acute sports injury assessment, the mechanism of injury must be considered when evaluating the injured athlete on the field as well as on the sidelines. The Sports Physical Therapist (PT) must look for these initial life threatening conditions as well as be aware of and monitor for the development of these symptoms during the subsequent evaluation of the athlete. These injuries may occur with both blunt trauma to the chest/thorax (more common) as well as with penetrating injuries (extremely rare occurrences in sporting events).

Typical signs and symptoms of chest injuries in athletics include dyspnea, signs of shock, a feeling of “impending doom” on the part of the athlete, hemoptysis, decreased breath sounds, irregular pulse, tracheal deviation and distended neck veins. Any of these symptoms may constitute a medical emergency and it is the responsibility of the Sports PT is to recognize the medical emergency, relay information to the emergency operator, and provide care for the athlete until more advanced medical personnel arrive.

Potential life threatening injuries and conditions that may be encountered include flail chest, open chest wounds, pneumothorax, tension pneumothorax, hemothorax, myocardial contusion, cardiac tamponade and diaphragmatic rupture. Each of these conditions is a possible occurrence in injuries sustained while participating in collision/contact sports. The Sports PT must be able to recognize the signs and symptoms of potentially life threatening injuries and proceed with safe and effective management of any of these when encountered.

Flail Chest

The condition known as flail chest occurs when one or more ribs are fractured in one or more places. Rib fractures are determined by palpation for bony abnormalities, localized tenderness, the feeling of “crepitus” or a grating feeling when the fracture sites move against one another. An additional method of determining the presence of a rib fracture is with the use of a tuning fork placed against each of the individual ribs of the athlete. A positive tuning fork test (indicating the possible presence of a fracture) is the sudden onset of acute pain in the rib(s) and the athlete suddenly moves away from the tuning fork complaining of the onset of sharp pain. (Figure 1)

Should the presence of multiple rib fractures be noted, the result may be the presence of what is known as **paradoxeax breathing**. On inhalation, the “flail” segment moves in an inward direction rather than expanding as in normal inspiration. As the player exhales, the “flail” segment will expand or rise rather than fall in a posterior direction if the athlete is supine. This could constitute a true medical emergency and the local emergency service should be contacted with information that the player may have a flail chest. If rib fractures are suspected, the athlete must be made comfortable, be monitored for signs and symptoms of shock, and have his/her respiratory effort monitored for rate and quality. The athlete should be transported to the local medical facility.

**Figure 1.** Graphic representation of multiple rib fractures, circled in red.
Open Chest Wounds

Open chest wounds rarely occur in sports. This injury is a result of an object (missile) penetrating the chest wall of the player. The result can be life threatening due to the collapse of the lung or penetration of other organs at the site of the injury. If penetration of the lung occurs, the therapist may hear a "sucking" sound which is termed a "sucking chest wound." That is, the sound of air being drawn into the chest through the opening in the chest wall, as opposed to through the mouth and nose. Proper action is to seal the wound with an air tight dressing, such as a piece of plastic, secured with tape on three sides. The fourth side must be left open to allow air to escape from the chest during exhalation. The EMS system should be promptly utilized to transport the athlete to the local medical facility.

Pneumothorax/Tension Pneumothorax

Tension pneumothorax occurs when the integrity of the lung tissue is compromised, allowing air to escape from the lung into the surrounding pleural tissue. This occurs when the lung tissue ruptures within the chest cavity, either with or without trauma. This results in increased pressure within the pleural space that provides external compression of the lung. (Figure 2)

If left untreated or unrecognized, respiratory effort may be compromised resulting in a lack of oxygenated blood being delivered to the vital organs of the body. Signs and symptoms of a pneumothorax include difficulty breathing, paleness or bluish discoloration of the skin, complaints of dizziness or nausea, vomiting, as well as pain in the chest which may radiate into the shoulders, upper extremities, or midscapular area. Two distinct physical signs occur with the pneumothorax; distended neck veins and tracheal deviation. Upon observation of the anterior aspect of the neck, one will note the distention of the veins present there. This is due to the increased pressure in the chest cavity and the inability of the venous blood to return easily from the head. The second sign is deviation of the trachea, which occurs away from the site of the chest in which the pneumothorax has occurred. This is also secondary to increased pressure within the chest cavity. This is a medical emergency and the athlete should be transported using the EMS system.

Myocardial Contusion

Myocardial contusion occurs when the athlete is struck in the anterior aspect of the chest in the region of the heart. This blow, most commonly with an object or missile, results in bruising of the heart muscle. Less commonly, the chest of the athlete is struck with a fist or elbow of another athlete. As a result of the contusion, the heart will bleed into the pericardial sac resulting in compression of the heart muscle. Symptoms initially include difficulty breathing that is slow to resolve, restlessness of the athlete, a possible contusion over the heart with resultant bruising, and most importantly cardiac tamponade. Assessment of cardiac function is performed by monitoring the blood pressure of the athlete. In cases of true cardiac tamponade, the diastolic and systolic blood pressure will become closer in number. For example, the initial blood pressure may be
160/70, when the pressure is taken at a later time the blood pressure becomes 150/80, then 140/90, then 130/100 with other concurrent symptoms such as chest pain, pain radiating into the left upper extremity and jaw as well as other signs of a myocardial infarction. This is a true medical emergency and the information regarding a possible cardiac tamponade should be relayed during the call to the emergency response operator. (Figure 3)

**Commotio Cordis**

Commotio Cordis also occurs when the athlete is struck in the chest with a missile or object, but differs from a myocardial contusion in that it occurs precisely at the beginning of the T-wave in the cardiac cycle.$^{1,2,6}$

This blow will immediately cause the heart to go into ventricular fibrillation which is life threatening. In their description of 70 cases of commotio cordis, Maron et al.$^6$ stated that the most common sports involved were youth baseball (n = 40), softball (n = 7), and ice hockey (n = 7). Seven (10%) of the 70 commotio cordis victims, including six with documented ventricular fibrillation, survived the consequences of their chest blow. Eleven of the events (16%) occurred despite the presence of chest padding believed to be potentially protective. The most effective way of restoring the normal cardiac cycle is with the use of the Automated External Defibrillator (AED).$^7$ Although extremely rare in sports, this can occur with sports such as baseball, softball, karate, or other collision and contact sports where a blow to the chest is possible. The Sports PT should be prepared to evaluate and manage this type of injury by having an AED present at all athletic events.$^7$ Failure to restore cardiac rhythm may cause death of an otherwise healthy, normal athlete.

**CONCLUSION**

Although extremely rare in athletics, life threatening chest injuries can and do occur. Initial care of the chest injury includes determination of the mechanism of injury, initial evaluation of the athlete’s airway, breathing, circulation, and level of consciousness. The safety of the scene must also be considered, but often is not a consideration in the sporting arena. Any deficits in the athlete’s airway, breathing and circulation must be addressed first during the initial care of the chest injured athlete. The Sports PT must be aware of the signs and symptoms of serious chest injuries, be well prepared to handle cardiac emergencies by having an AED present, and be able to competently activate the emergency medical system. The Sports PT must also be able to monitor athlete’s status and provide necessary emergency care until EMS arrives.

**REFERENCES**

ABSTRACT

Background: A battery of tests is commonly used to measure disability with and recovery from concussion. A number of different concussion-oriented assessment tests exist and each is considered useful. To the authors' knowledge, no study has compared the scores of these tests during recovery in the middle school and high school aged population to see how each change over time.

Purpose: The purposes of this study were to analyze clinical data of concussed middle school and high school aged athletes to determine the concurrent and predictive validity for post-concussion syndrome (PCS) of the Post-Concussion Symptom Scale (PCSS), Balance Error Scoring System (BESS), and the five subscales of the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT).

Methods: The study was a retrospective chart review performed on middle school and high school aged individuals with a diagnosis of concussion from the years 2008-2010 within the Akron Children's Hospital Sports Medicine system. To be eligible for inclusion in the dataset, each subject required a baseline measurement for each of the three tests (and all five subscales of the ImPACT) and a post-test measure. The mean age of the population was 15.38 years (SD = 1.7) and ranged from 11 to 19 years. Pearson product correlation tests (correlation matrix) were used to analyze the concurrent validity of the test items during recovery following a concussion. Receiver operating characteristics (ROC) curves were used to determine the predictive validity of initial scores for developing PCS.

Results: The correlation matrix captured five statistically significant findings; however, these suggested only weak to mild correlations. Five test items yielded an area under the curve (AUC) greater than 0.50 but only one was statistically significant. After qualitative evaluation, only one of the three tests (including the five subscales of the ImPACT) was useful in predicting post-concussion syndrome.

Conclusion: This study suggests that there is poor concurrent validity among three commonly used concussion tests and there is no baseline score that predicts whether post-concussion syndrome will occur.

Level of Evidence: 2b

Key Words: Concussion, Diagnostic accuracy, Post-concussion syndrome, Validity
INTRODUCTION

There are an estimated 1.7 million traumatic brain injuries (TBIs) each year in the United States, of these 1.36 million are treated and released from an emergency room setting. Approximately 75% of TBI cases are classified as a mild traumatic brain injury or concussion. TBIs cost the country approximately $17 billion dollars annually. Of all the concussions that occur each year, 300,000 are a result of playing a sport. An estimated 55.2% of all high school aged students in the country participate in some form of an organized sport, thus the potential for concussions for this population during sporting events yearly is exceptionally high.

A concussion has been defined as a complex pathophysiological process that occurs from a blow to the head, face, or neck, in which the force is transferred to the head. The concussion affects the brain and can lead to a rapid onset of short-lived impairments that are not always seen via imaging. Recognition of symptoms associated with concussion is imperative for the health care provider. Post-concussion syndrome (PCS) is a poorly understood and typically non-life threatening condition, which occurs when concussive symptoms are prolonged for weeks or potentially months after the injury that caused the concussion. Post-concussion syndrome is generally treated by providing information, education, and reassurance but may also include pharmacologic therapies designed to reduce prolonged symptoms such as sleep disturbances or anxiety. Second impact syndrome is a disorder where the brain swells rapidly after a person suffers a second concussion before symptoms from an earlier concussion have subsided, is life threatening and differs significantly from post-concussion syndrome. The occurrence of second impact syndrome has been documented almost exclusively in immature brains, which suggests that young athletes are at the greatest risk. To decrease this risk, clinical management of concussion has included restriction of participation in physically and mentally stressful activities until the individual is asymptomatic.

A battery of tests is commonly used to determine post-concussion recovery, which includes neurocognitive testing, postural stability assessment, and self-reported concussion symptoms. A battery is recommend for a comprehensive assessment because the tools lack sensitivity and often fail to accurately identify positive findings in acute concussion cases diagnosed by a physician. Several studies have looked at the relationships between the individual tests and there is a general consensus that the constructs of each are important and unique in the assessment of concussion. To the authors knowledge, no study has compared the scores of these tests during recovery in the middle school and high school aged population to see if each changes over time.

It has been suggested that the initial resolution of self-reported concussive symptoms may not be indicative of full recovery. Evidence exists that neurocognitive deficits remain for as many as 14 days even if the adolescent is not reporting any symptoms. In addition, it has been reported that anywhere from 15 to 50% of individuals who sustain a concussion experience prolonged symptoms and are diagnosed with (PCS). Although no current diagnostic criterion is universally agreed upon, most PCS diagnoses include a history of head injury, a dedicated time parameter of continued symptoms, and resultant behavioral criteria such as headache, apathy, irritability, dizziness and fatigue. Even though these criteria exist for guidance, the final PCS diagnosis has historically been a clinical diagnosis which runs the risk of variability among physicians. At present, few studies have examined baseline predictors of PCS and outside of gender, litigation, and neurocognitive testing, there is little evidence to identify individuals who may be at risk for developing PCS using clinical testing. Neurocognitive testing is recommended to help aid in the diagnosis of concussion and return to activity decisions, and is becoming increasingly popular to ensure that full recovery has been achieved. Clinical testing, using methods commonly employed by practicing clinicians often involves measures of balance, agility, dexterity, and computer-related tasks.

The purpose of this study was to retrospectively analyze clinical data of concussed middle school and high school aged individuals from a regional children’s hospital to determine if there was concurrent validity among three commonly used tests for assessing concussion, and how these test scores changed over time following the injury. In addition, a goal was to determine if there is predictive validity of any of these test scores at baseline to be able to predict a subsequent diagnosis of post-concussion syndrome.
that the patient rates on a scale between 0 to 6 with 0 indicating the absence of that symptom and 6 indicating a severe presence of the symptom. Lovell et al have shown the PCSS to be a reliable test with an internal consistency reliability of 0.93.

**Balance Error Scoring System (BESS)**

The BESS is an assessment tool used for an inexpensive assessment of postural stability. The test includes single, double, and tandem stance assessment on firm and foam (unstable) surfaces, each held for 20 seconds, with the athlete's hands on hips and eyes closed. The BESS is the most widely used balance assessment tool for concussion evaluation and management and is based on the premise that concussion injuries lead to a decline in postural stability and an increase in measurable postural sway during fatigue or intentional demands. The BESS has been shown to be a reliable and valid clinical tool to help determine balance deficits after head trauma with an intrarater reliability ranging from 0.74 to 0.87 and an interrater reliability of 0.57 which improved to 0.98 with serial administration.

**Immediate Post-Concussion and Cognitive Testing (ImPACT)**

The ImPACT is the most widely used computerized neurocognitive test. The test has several subscales that evaluate intentional processes, verbal recognition memory, visual working memory, visual processing speed, reaction time, numeric sequencing ability and learning. Research has shown that the ImPACT test is both reliable and stable with a test-retest reliability ranging from 0.65 to 0.86 in comparison to other neurocognitive tests. The sensitivity of the ImPACT test was determined to be 81.9% and the specificity was 89.4% to rule a concussion in or out.

**Statistical Procedures**

All statistical analyses were performed using Predictive Analytics Software (PASW) Statistics version 18.0.1. The descriptive statistics were reported after running frequency distributions, mean and standard deviations when applicable. Pearson product correlation tests (in the form of a correlation matrix) were used to analyze the concurrent validity of the BESS, PCSS and individual items on the ImPACT during recovery following a concussion. Change scores were used to represent the BESS, PCSS, and ImPACT score.
subscores. Correlational strength was defined as: $<0.25 = \text{little or no relationship}, 0.25–0.50 = \text{fair relationship}, 0.50–0.75 \text{ moderate to good relationship and } >0.75 = \text{good to excellent relationship.}^{39}$

Receiver Operating Curve (ROC) statistics were used to identify cut-points within each initial concussion measure to an end point measure of post-concussive syndrome. ROC curve values, including area under the curve (AUC) were calculated (in lieu of regression analyses), because each baseline score represented a continuous data point and the authors were interested in determining whether a cut point or dedicated baseline value was associated with a long-term diagnosis of PCS. AUC measures range from .50 to 1.0, with values closer to 1.0 reflecting stronger relationships. Values below .50 reflect an inverse or negative relationship. For all analyses, an alpha value of $\leq0.05$ was considered statistically significant.

### RESULTS

Following the review of all available charts with a diagnosis of concussion between the years of 2008 to 2010 the medical records of 106 patients satisfied the inclusion criteria. The mean age of the population was 15.38 years (SD=1.7) and ranged from 11 to 19 years. The study population consisted of 65% males and 35% females. Of the 69 males, 38 (55%) were subsequently diagnosed with PCS whereas 17 of the 37 (46%) females were diagnosed with PCS; accounting for 51.9% of the total sample. Of the 106 individuals included in the study, 40.6% of patients previously suffered a diagnosed concussion and 12.3% had suffered multiple concussions. A majority of the concussions occurred during an athletic event with football as the sport with the greatest number of concussions at 33.0%, followed by basketball and soccer at 11.3% and 10.4% respectively. Most (59%) of concussions were first time events, followed by 28.3% which was second concussions, 8.5% which were third concussions, 2.8% which were the fourth reported concussion, and less that 1% indicating a fifth concussion. The duration of care ranged from 2 to 97 days with a mean of 15.5 days (SD = 14.1). There was no single standard of care for all patients and treatment processes were variable. Table 1 outlines the descriptive statistics of the sample.

The results from the Pearson product correlation matrix are found in Table 2. The correlation matrix captured five statistically significant findings. Mild correlations existed between the change scores of the BESS and ImPACT Impulse Control ($r = -0.31; p = .002$) and also between the change scores of the BESS and ImPACT Verbal ($r = 0.37; p = .000$). The ImPACT Impulse Control score also demonstrated a weak correlation with the ImPACT Visual ($r = -0.24; p = .015$) and Verbal change scores ($r = -0.22; p = .026$). Lastly, the ImPACT Verbal and Visual change scores demonstrated a mild correlation ($r = 0.31; p = .001$).

When assessing the ROC baseline cut points, 5 of the findings found in Table 3 yielded an area under the curve (AUC) greater than 0.50, but only one was statistically significant. The PCSS yielded an AUC of 0.34, suggesting an inverse relationship with PCS (lower baseline scores are more commonly associated with PCS). The results of the ROC curves are displayed in Table 3.

### DISCUSSION

The purpose of this study was to determine the concurrent validity of the change scores of the ImPACT,
BESS and PCSS, as well as determine the predictive validity of this battery of tests along with the duration of treatment and a history of previous concussions in determining PCS. Neurocognitive testing, which involves examination methods that are not routinely available to a practicing sports medicine clinician, along with a balance assessment and a self-reported symptom scale (two methods available and frequently used), are commonly used to evaluate patients after a concussion and have been widely recommended for determining when an individual can return to normal activity.\textsuperscript{8,10,12,14-16} To the best of the authors knowledge, no study to date has examined the concurrent validity and predictive validity of clinical testing of the BESS, PCSS, or ImPACT scores in the middle school and high school aged population.

This study found low concurrent validity between the change scores of the battery of tests despite the fact that there were five statistically significant results in the correlation matrix. The test items in the correlation matrix that were most closely related were the

### Table 2. Correlation Matrix (7X7) Table for Change Score for Concussion Assessment.

<table>
<thead>
<tr>
<th></th>
<th>Bess change score</th>
<th>PCSS change</th>
<th>IMPACT Impulse Control change</th>
<th>IMPACT Visual Motor Speed change</th>
<th>IMPACT Reaction Time change</th>
<th>IMPACT Visual Score change</th>
<th>IMPACT Verbal change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bess change score</td>
<td></td>
<td>Pearson Correlation</td>
<td>Sig. (2-tailed)</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>N</td>
<td>106</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCSS change</td>
<td></td>
<td>Pearson Correlation</td>
<td>Sig. (2-tailed)</td>
<td>-.147</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>N</td>
<td>106</td>
<td>106</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMPACT Impulse Control change</td>
<td></td>
<td>Pearson Correlation</td>
<td>Sig. (2-tailed)</td>
<td>-.306$^*$</td>
<td>-.147</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>N</td>
<td>105</td>
<td>105</td>
<td>105</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>IMPACT Visual Motor Speed change</td>
<td></td>
<td>Pearson Correlation</td>
<td>Sig. (2-tailed)</td>
<td>-.033</td>
<td>-.077</td>
<td>-.087</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N</td>
<td>105</td>
<td>105</td>
<td>105</td>
<td>105</td>
<td>105</td>
</tr>
<tr>
<td>IMPACT Reaction Time change</td>
<td></td>
<td>Pearson Correlation</td>
<td>Sig. (2-tailed)</td>
<td>-.018</td>
<td>-.131</td>
<td>-.002</td>
<td>-.023</td>
</tr>
<tr>
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<td>105</td>
<td>105</td>
<td>105</td>
<td>105</td>
<td>105</td>
</tr>
<tr>
<td>IMPACT Visual Score change</td>
<td></td>
<td>Pearson Correlation</td>
<td>Sig. (2-tailed)</td>
<td>.614$^*$</td>
<td>.163</td>
<td>-.217$^*$</td>
<td>.073</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N</td>
<td>106</td>
<td>106</td>
<td>106</td>
<td>106</td>
<td>106</td>
</tr>
<tr>
<td>IMPACT Verbal change</td>
<td></td>
<td>Pearson Correlation</td>
<td>Sig. (2-tailed)</td>
<td>.000$^*$</td>
<td>.094</td>
<td>.026</td>
<td>.455</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N</td>
<td>106</td>
<td>106</td>
<td>106</td>
<td>106</td>
<td>106</td>
</tr>
</tbody>
</table>

$^*$Correlation is significant at the 0.05 level (2-tailed).

$^*$Correlation is significant at the 0.01 level (2-tailed).

### Table 3. ROC-Area under the curve (AUC) analysis for predictive validity of PCS.

<table>
<thead>
<tr>
<th>Test</th>
<th>Area Under the Curve (AUC)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCSS Initial Score</td>
<td>.377$^*$</td>
<td>.03$^*$</td>
</tr>
<tr>
<td>BESS Initial Score</td>
<td>.481</td>
<td>.733</td>
</tr>
<tr>
<td>ImPACT Impulse Control Initial Score</td>
<td>.447</td>
<td>.351</td>
</tr>
<tr>
<td>ImPACT Verbal Initial Score</td>
<td>.535</td>
<td>.538</td>
</tr>
<tr>
<td>ImPACT Visual Initial Score</td>
<td>.556</td>
<td>.319</td>
</tr>
<tr>
<td>ImPACT Reaction Time Initial Score</td>
<td>.544</td>
<td>.433</td>
</tr>
<tr>
<td>ImPACT Visual Motor Initial Score</td>
<td>.555</td>
<td>.325</td>
</tr>
<tr>
<td>Duration of Treatment</td>
<td>.571</td>
<td>.643</td>
</tr>
<tr>
<td>History of Concussion</td>
<td>.494</td>
<td>.919</td>
</tr>
</tbody>
</table>

$^*$Significant at the p ≤.05 level
ImPACT verbal change score and the BESS change score with $r = 0.37$; however, this only represents a fair correlation. The other relationships found in the correlation matrix ranged from weak to mild. At present, it is suggested that the use of a battery of tests to assess recovery and provide guidance for the return to activity following a concussion is the most meaningful and discriminative method for appropriate clinical practice. The results of this study lend tangential support to this suggestion, as improvement in one test did not correlate strongly with improvement in any of the other tests included in this study. The current findings are similar to those from a previous study performed with college athletes that found that not all concussion tests scores for an individual with a concussion improve at a similar rate. A myriad of symptoms are present following a concussion and the variable tests may be necessary to capture all of the potential representations.

The second major finding in this study is that there is no evidence that a baseline score of the BESS, ImPACT, or PCSS had the ability to accurately identify individuals who will be diagnosed with PCS at a later date. The PCSS was the only measure with a statistically significant ROC curve, however, the area under the curve was 0.38, which suggests those with a higher PCSS score (indicating greater severity of injury), have a decreased likelihood of developing PCS (and vice versa). These findings are counterintuitive, and it is unlikely that a patient with a lower initial PCSS score is more likely to develop PCS when compared to a patient with a higher initial score. Ironically, this finding is consistent with findings reported in a systematic review by Carroll et al. who concluded the long term prognosis for persistent symptoms following a concussion may be attributable to factors other than the severity of initial impairments.

Another possible explanation for this curious result is that there is uncertainty in the literature of the definition of PCS. PCS is a clinical diagnosis, representing signs and symptoms and a subsequent decision made by a physician. The current study utilized medical charts from multiple physicians and because PCS is a clinical diagnosis and is considered a syndrome, the diagnosis may have varied from one physician to another. Another possible explanation is that subjects with higher initial scores on the PCSS may have been treated more conservatively. The typical protocol following a concussion is physical and mental rest. The individuals with few impairments, as measured by the battery of tests, may have begun activity earlier than those with multiple impairments, or they may not have followed the protocol as closely because they were less symptomatic.

**Limitations**

This study was retrospective in nature, which reduces the amount of control over extraneous variables such as post-concussive treatment. This is evident by the large variance in time from initial visit to final visit. Also, the inclusion criteria required subjects to have at least two visits during a single episode of care in which all three of the tests were performed. There is the risk that certain subjects performed these tests multiple times because of poor performance during the initial test. This may have skewed the data to include patients with a higher level of impairment. Also, the patients who were experiencing less impairment after a single visit may not have returned for a second visit.

**CONCLUSION**

Following a concussion injury (in this sample of middle and high school aged athletes), a single clinical measurement tool does not appear to be adequate in order to accurately determine whether the resolution of symptoms and impairments is sufficient to permit a full return to activity. It is important to monitor progress using a battery of tests to ensure confidence of clinical decision making. Most concussion oriented clinical tests do not appear to have any predictive value for determining the risk of an individual for experiencing prolonged post-concussive symptoms. Future research is needed to identify variables that are associated with PCS and until this is more clearly identified individuals with concussion injuries should be treated with extreme caution and careful assessment should be conducted prior to return to activity.

**REFERENCES**

1. Faul M, Xu L, Wald MM, Coronado VG. Traumatic brain injury in the United States: emergency department visits, hospitalizations, and deaths. Atlanta (GA): Centers for Disease Control and
Prevention, National Center for Injury Prevention and Control; 2010.


42. McGrath N. Supporting the student athletes return to the classroom after a sport-related concussion. *J Athl Train* 2010;45(5):492-8.
ABSTRACT

Purpose/Background: Some physical therapists (PTs) provide services at sporting events, but there are limited studies investigating whether PTs are properly prepared to provide such services. The purpose of this study was to assess acute sports injury and medical condition management decision-making skills of PTs.

Methods: A Web-based survey presented 17 case scenarios related to acute medical conditions and sport injuries. PTs from the Sports Physical Therapy Section of The American Physical Therapy Association were e-mailed a cover letter/Web link to the survey and invited to participate over a 30-day period. Data were analyzed using SPSS 18.0.

Results: A total of 411 of 5158 PTs who were members of the Sports Physical Therapy Association in 2009 and had valid e-mail addresses completed the survey, of which 389 (7.5%) were appropriate for analysis. Over 75.0% of respondents felt “prepared” or “somewhat prepared” to provide immediate care for 13 out of 16 medical conditions, with seizures, spinal cord injuries, and internal organ injuries having the lowest percentages. Over 75.0% of the respondents made “appropriate” or “overly cautious” decisions for 11 of the 17 acute injury or medical condition cases.

Conclusions: Results of the current study indicate that PTs felt more “prepared” and tended to make “appropriate” return to play decisions on the acute sports injury and medical condition case studies more often than coaches who participated in a similar study, regardless of level of importance of the game or whether the athlete was a starter vs. non-starter. However, for PTs who plan on assisting at sporting events, additional preparation/education may be recommended, such as what is taught in an emergency responder course.

Key Words: Acute sports injury management, return to play decisions

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INTRODUCTION

Athletic Injuries
High school (HS) athletics play an important role in the overall health and fitness of student athletes. More than 7.6 million HS students participated in athletics in the United States during the 2009-2010 seasons. With participation in sport comes a risk of injury. In fact, results of a 2005-2006 study indicated that injuries in HS athletics occurred at a rate of 2.4 injuries per 1000 athlete exposures, including both practices and games. It is estimated that HS athletes account for about approximately 2 million injuries, 500,000 doctor visits, and 30,000 hospitalizations per year. In 1997-98, there were an estimated 2.6 million sports related injuries which required emergency room visits by people aged 5 to 24 years. In fact, sports related injuries accounted for 22.0% of total visits to the emergency room; 9.8% of the injuries occurring in group sporting activities and 12.2% of injuries occurring in individual sport activities. Various authors have suggested that the number of actual injuries experienced in HS athletics is most likely higher than published statistics due to the fact that many injuries go unreported or undocumented. According to data provided by the Injury Cost Model of the U.S. Consumers Product Safety Commission, injuries sustained during the top 5 male and female HS sports cost an estimated $5.88 million in direct expenses and $6.6 billion in indirect expenses. With the number of athletic injuries increasing, there is a need to examine the types of medical assistance available and the knowledge of acute injury management and assessment of those who provide such assistance.

Medical Coverage
Much of the medical coverage at HS athletic events is provided as a means of security and safety because there has not been any verification that medical coverage actually reduces the number of injuries that are sustained. Having coverage at athletic events can allow for proper and quick diagnosis, treatment, and care to be supplied to the injured athlete. If appropriate care is rendered immediately, the chances of the injury worsening are reduced and an environment that promotes healing and recovery of the injury can be established.

Although every team would ideally have appropriate medical personnel at every practice and competition, rarely is this the case. Even when a school has appropriate personnel, sufficient medical coverage may not always be an option due to schools having several athletic teams, of varied levels, that practice or compete simultaneously. The team medical staff may attend the athletic competitions of varsity athletics only, and if there are multiple sporting events at the same time, the result is usually a shortage of medical personnel. In a 2007 study by Olympia et al, questionnaires were sent to 1000 randomly selected members of the National Athletic Trainers Association and the results revealed that only 34% of the schools had an athletic trainer (ATC) present for all athletic events. These numbers are similar to the findings of a study conducted in South Dakota in which only 36% of the coaches reporting having an ATC at home competitions. Although Aukerman et al found that a higher percentage of schools had coverage by an athletic trainer and/or physician, 49% of school officials in North Carolina indicated their school’s medical coverage of athletics was inadequate.

When medical support and/or coverage in HS athletics is insufficient or unavailable for 1 reason or another, the administration, athletes, and parents often look to the coach to assume the responsibility of determining if a player is injured and providing emergency medical care for the athletes on their team(s). In a study conducted by Cross and colleagues with HS head coaches in South Dakota, less than 75.0% of participants perceived feeling “prepared” or “somewhat prepared” to handle 11 of the 16 categories of injuries or medical conditions presented. In addition, less than 75.0% of coaches surveyed gave “appropriate” or “overly cautious” responses to 8 of the 17 case scenarios. Even when the coaches noted they felt “prepared” or “somewhat prepared” to handle a certain type of injury, the level of preparedness did not always result in making an “appropriate” management decision. Part of these findings may be attributed to the fact that even if a coach feels prepared to handle an acute injury, the desire to win may influence the decision making capabilities of the coach. In fact, Cross et al found that coaches made “appropriate” return-to-play decisions 66.5% of the time during important events (conference game/meet or tournament) and 76.6% of the time in less important events.
Physical Therapists

The scope of practice of physical therapists (PTs) is determined by state licensing laws. Some state practice acts allow therapists to function as a primary care provider (PCP), which allows therapists to diagnose and treat injuries without a referral from a physician or other primary care provider; others do not. As of August 2011, 46 states had direct access laws for PTs; however, some states had limitations or provisions related to their Practice Act. In states in which PTs may practice as PCPs, they do so in various settings. Various studies have also indicated positive outcomes, patient satisfaction, and cost effectiveness for various conditions and in various settings when a PT functions as a PCP.

*Return to play decisions are a core responsibility of team physicians and sport medicine practitioners.* Parents, coaches, and athletes expect medical providers to be competent in injury management and return-to-play decision making. While physical therapists (PTs) have the education and knowledge to make decisions concerning the care of an injured athlete, including providing interventions that assist in returning an injured athlete to sport participation, it is traditionally thought that their expertise is best utilized in a clinical setting. Many PTs who work in sports medicine practice in a clinical setting have time to fully evaluate, treat, and rehabilitate the athlete. In contrast, PTs who are employed by schools to cover practices or competitions, and serve as a PCP through direct access laws, need to make decisions related to injury severity and return to play in a much shorter time frame.

With additional autonomy comes an additional legal responsibility to the athletes that PTs screen. Potential liability issues can arise when diagnosing and treating injuries that manifest during competition or practice, including making return to play decisions after assessment and treatment, getting informed consent, suggesting recommendations for and follow-up medical care and assessments, operating under HIPPA policy, and being negligent. Other areas where sport PTs need to be careful with regard to liability include allowing the athlete to participate in sports before an athlete is ready and/or the injury is fully healed, failing to inform an athlete of potential risks of continuing participation in sport with his/her condition, and failing to properly educate an athlete on his/her ability to return to sport. A PT should use objective criteria when deciding whether or not to return an athlete to competition, while keeping players’, coaches’, and PTs’ emotions and beliefs out of the decision. In the event that an athlete is returned to competition without proper recovery from an injury, the PT responsible for this athlete can be held liable for negligence. Additionally, should a PT try to treat an athletic injury which he/she does not possess the specific skill set to treat, the PT can also be held negligent for practicing outside of his/her expertise as it is the job of any coach or medical provider covering an athletic event to ensure that the inherent risks of the sport are not increased. On the other hand, if a PT works within his or her specific scope of practice, acts in the best interest of the athlete, and uses sound judgment, the PT should not be held accountable for negligence should an injury occur, as he/she was acting in good faith.

One way a PT may reduce the risk of a lawsuit is through education and providing a record of ongoing competence in important skills related to the practice of sports physical therapy. According to the Sports Physical Therapy Section (SPTS) Web site, sports therapists should be competent in, prevention, evaluation, treatment, rehabilitation, and performance enhancement of the physically-active individual. The prevention aspect of practice includes performance of pre-participation screening, knowledge of equipment use, as well as prescription of cardiovascular fitness programs aimed at returning athletes back to competition as quickly and safely as possible. The evaluation and treatment components focus on recognizing and treating acute and chronic injuries, especially neuromuscular and musculoskeletal injuries. Sports PTs should also have the knowledge to assist athletes in improving performance by recognizing individual athlete’s strengths and weaknesses. Related to these areas of sports physical therapy practice, a certification is available through the American Board of Physical Therapy Specialists (ABPTS) that labels therapists as sports physical therapy specialists. As of February 2011, 854 PTs were certified as sports specialists (SCS) through the ABPTS. In order to attain the
initial certification a therapist must provide at least 2000 hours of direct patient care in a sports therapy setting within the last 10 years (500 of which must have occurred in the last 3 years) or complete an American Physical Therapy Association (APTA) credentialed post professional sports clinical residency; complete appropriate CPR certification; possess certification as either an emergency medical technician (EMT), paramedic, ATC, or an American Red Cross (ARC) Emergency Responder; and pass a national examination. The ARC Emergency Response Course, which will have an enhanced curriculum and be renamed the Emergency Medical Responder Course starting in the Summer of 2011, helps train PTs in the evaluation and care of acute injuries and illnesses, including those that may be encountered by a PT at athletic events, in clinical settings, or in the community. Results of various studies have indicated that there is a lack of qualified medical professionals who assist with HS sports coverage. As participation in HS athletics continues to rise, it may be imperative that additional health professionals, including PTs, become active and are competent in acute injury management and clinical decision making. According to Smith, "Frequently, the sports physical therapist (PT) is the 'most medical' individual present at athletic events, especially at HS, middle school, and club level athletic events." In fact, HR 469, which was introduced in the House of Representatives on January 26, 2011, lists PT's as one of the health care professionals who could determine if a school-aged child could return to play after a concussion.

Due to the lack of research related to PTs practicing "on the sidelines," the purpose of this study was to assess the decision making skills of PTs related to the management of acute sports injuries and medical conditions. The primary objective was to assess decision making skills related to acute injury and medical condition management of PTs through the use of case scenarios. Secondary objectives were to: 1) assess the relationship between appropriateness of the specific game scenario decision and the respondents' beliefs regarding their preparedness to manage various medical conditions, and 2) analyze the relationship between appropriateness of the game scenario decisions based on game situation and level of the athlete.

**METHODS**

**Research Design**

This study was a descriptive Web-based survey. The participants completed the survey via SurveyMonkey, a Web-based medium.

**Subjects**

The subject pool consisted of individuals who were members of the SPTS of the APTA in September 2009. The inclusion criteria were PTs who were members of the APTA as well as the SPTS (n = 5621) (Robert Manske, DPT, e-mail communication, August 5, 2011). The exclusion criteria were PTs who were not members of the APTA; PTs who were members of the APTA, but not members of the SPTS; PTs who were members of both the APTA and the SPTS, but did not have valid e-mail addresses with the SPTS; and members of the SPTS who were not PTs. An e-mail was sent to the SPTS e-mail distribution list (n = 6771) inviting individuals to participate in the study if they were a PT. This e-mail contained the link to the anonymous Web-based survey on SurveyMonkey. The original e-mail distribution list provided by the SPTS included all SPTS members with an e-mail address, including physical therapist assistants (n = 232) and students (n = 947) (Robert Manske, DPT, e-mail communication, August 5, 2011). Twenty-nine PTs did not have e-mail addresses listed with the SPTS and 434 e-mails sent out to PTs came back to the sender as undeliverable. Therefore, out of the 5621 PTs who were members of the SPTS in September 2009, 5158 were eligible to participate in this study (91.8% of PTs in the SPTS), of which 411 individuals (8.0%) completed the survey. If an individual did not complete at least 50.0% of the case scenarios (9 scenarios), the survey was not included in the data analysis. Therefore, 389/5158 (7.5%) were usable surveys and were included in the data analysis.

**Instruments**

Cross and colleagues created a survey, utilizing validated acute sports injury case studies, to assess the level of preparedness, as well as the decision making, of HS coaches for various acute sports injuries and medical conditions. Permission to use the survey and modify the demographic information questions to be applicable to PTs was granted by Cross and colleagues. The demographic section of the survey was
modified to include questions related to current employment status, primary practice setting, years of practice, specialty certifications held, and years of providing sports physical therapy services in clinical and acute sports settings; the specific case studies were not modified.

Procedures
The project was submitted and approved by the home Institutional Review Board of the researchers, of which all the authors were associated with at the time. All subjects were sent a cover letter and a link to the survey via an e-mail. A reminder e-mail was sent after the survey had been open for 2 weeks. The survey was available from December 14, 2009 to January 18, 2010. Consent was implied by participants clicking the link to start the survey. Participants were able to leave answers blank if they chose to do so. Participants were given the opportunity to contact the primary authors and submit their names for a gift-certificate drawing after completion of the study.

Statistical Methods
Frequencies and percentages were calculated for demographic information, employment/practice settings, types and levels (youth, HS, college, amateur, professional) of sports coverage, personnel providing coverage at practice and competitions, certifications, perceived preparedness related to acute injury management, and responses to the case scenarios.

For each of the case scenarios, the PTs chose from 4 different options: “hold out and refer,” “hold out and monitor symptoms,” “return to competition and monitor,” or “return to competition and not monitor.” In accordance with procedures established in the study by Cross and colleagues, case scenario responses were coded into 3 types: 1) “inappropriate,” 2) “appropriate,” or 3) “overly cautious.” Spearman correlations were used to analyze the relationship between the type of decision and appropriateness of the response to a case scenario to the level of preparedness of PTs managing various injuries. Each case scenario included variability in the situation, such as the level of the athlete (starter vs. non-starter) and the game scenario (important game/meet [i.e. conference game or state tournament] vs. non-important game/meet [i.e. pre-season or non-conference game]) as determined by Cross and colleagues. Chi-square statistics were utilized to determine differences in the appropriateness of PTs’ decisions based on the level of the athlete and the game situation. For cases that had level of athlete and game scenario variables, all of the cases were analyzed as a single group to determine the overall appropriateness of PTs’ decisions relevant to those variables. Additional chi-square statistics were utilized to determine differences between those who were or were not certified at the time as an EMT or paramedic, ATC, first or emergency responder and “appropriate” responses for each of the 17 cases, as well as between years of providing acute sports coverage and “appropriate” responses for the 17 cases. In cases in which a respondent was currently dual certified as an ATC, paramedic, EMT, or first/emergency responder, the highest level of certification and its relationship to acute sports injuries was utilized for reporting, with certification as an ATC ranked the highest and the rest ranked according to the National Highway Traffic Safety Administration’s levels of training (i.e. paramedic, EMT, then first responder). If an individual did not give an answer (previously, currently, or never) to any of the certifications listed (n = 29), those individuals were not included for this specific statistical analysis, but if an individual answered “currently” or “previously” to 1 or more of the certification questions and left the ATC, paramedic, EMT, or first responder certifications questions blank, then it was assumed that individual did not have 1 of these certifications. Due to the fact that only 1 participant responded to currently being a paramedic, the paramedic and EMTs were combined into 1 category for purposes of statistical analysis. Alpha was set to .05 for all statistical tests. All the data analysis was completed using the Statistical Package for the Social Sciences version 18.0.

RESULTS
Of the original 411/5158 (8.0%) PTs who submitted the survey, 22 surveys were excluded from data analysis due to the respondent not completing at least 50.0% of the cases. Therefore, there were a total of 389/5158 completed surveys, for a return rate of 7.5%. Of the respondents, 66.0% were males and 34.0% were females (Table 1). Reported current certifications included: 25.4% as an ATC, 87.1% in CPR, 20.1% as a first responders, and 17.5% as a SCS. Refer to Table 2 for reporting of all certifications. Of the
Table 1. Demographic information.

<table>
<thead>
<tr>
<th>Category</th>
<th>n (%)</th>
<th>Category</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (n=373)</td>
<td></td>
<td>Age (n=369)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>246 (66.0)</td>
<td>Under 25</td>
<td>14 (3.8)</td>
</tr>
<tr>
<td>Female</td>
<td>127 (34.0)</td>
<td>25-29</td>
<td>65 (17.6)</td>
</tr>
<tr>
<td>Highest Degree Earned (n=371)</td>
<td></td>
<td>30-34</td>
<td>64 (17.3)</td>
</tr>
<tr>
<td>Baccalaureate</td>
<td>70 (18.9)</td>
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<td>54 (14.6)</td>
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<tr>
<td>Master’s</td>
<td>125 (33.7)</td>
<td>40-44</td>
<td>43 (11.7)</td>
</tr>
<tr>
<td>PhD (or equivalent)</td>
<td>23 (6.2)</td>
<td>45-49</td>
<td>40 (10.8)</td>
</tr>
<tr>
<td>DPT (entry-level)</td>
<td>85 (22.9)</td>
<td>50-54</td>
<td>47 (12.7)</td>
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<tr>
<td>tdPT (transition)</td>
<td>58 (15.6)</td>
<td>55-59</td>
<td>27 (7.3)</td>
</tr>
<tr>
<td>PhD (or equivalent) &amp; DPT</td>
<td>3 (0.8)</td>
<td>60-64</td>
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<tr>
<td>Other</td>
<td>7 (1.9)</td>
<td>65+</td>
<td>4 (1.1)</td>
</tr>
<tr>
<td>Current Employment Status (n=369)</td>
<td></td>
<td>Years of Practice (n=369)</td>
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</tr>
<tr>
<td>Full-time salaried</td>
<td>255 (69.1)</td>
<td>&lt; 1</td>
<td>34 (9.2)</td>
</tr>
<tr>
<td>Part-time salaried</td>
<td>9 (2.4)</td>
<td>1-3</td>
<td>53 (14.4)</td>
</tr>
<tr>
<td>Full-time self employed</td>
<td>49 (13.3)</td>
<td>4-5</td>
<td>21 (5.7)</td>
</tr>
<tr>
<td>Part-time self employed</td>
<td>1 (0.3)</td>
<td>6-10</td>
<td>62 (16.8)</td>
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<tr>
<td>Full-time hourly</td>
<td>23 (6.2)</td>
<td>11-15</td>
<td>50 (13.6)</td>
</tr>
<tr>
<td>Part-time hourly</td>
<td>11 (3.0)</td>
<td>16-20</td>
<td>38 (10.3)</td>
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<tr>
<td>Retired</td>
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<td>78 (21.1)</td>
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<tr>
<td>Unemployed/not seeking work</td>
<td>12 (3.3)</td>
<td>31+</td>
<td>33 (8.9)</td>
</tr>
<tr>
<td>Unemployed/seeking full-time</td>
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<td>Primary Practice Setting (n=371)</td>
<td></td>
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<tr>
<td>Unemployed/seeking part-time</td>
<td>2 (0.5)</td>
<td>Acute care hospital</td>
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</tr>
<tr>
<td>Population of Town of Primary Practice Setting (n=360)</td>
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<td>Subacute rehab hospital</td>
<td>4 (1.1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Health system or hospital-based OP facility or clinic</td>
<td>90 (24.3)</td>
</tr>
<tr>
<td>1000-4999</td>
<td>23 (6.4)</td>
<td>Private OP or group practice</td>
<td>198 (53.4)</td>
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<tr>
<td>5000-9999</td>
<td>32 (8.9)</td>
<td>SNF/ECF/ICF</td>
<td>4 (1.1)</td>
</tr>
<tr>
<td>10,000-24,999</td>
<td>52 (14.4)</td>
<td>Patient’s home/home care</td>
<td>5 (1.3)</td>
</tr>
<tr>
<td>25,000-49,999</td>
<td>49 (13.6)</td>
<td>School system</td>
<td>3 (0.8)</td>
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<tr>
<td>Greater than 50,000</td>
<td>204 (56.7)</td>
<td>Academic institution</td>
<td>32 (8.6)</td>
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<tr>
<td>Population of Town Where Acute Sports Physical Therapy is Provided* (n=389 for each response)</td>
<td></td>
<td>Health and wellness facility</td>
<td>3 (0.8)</td>
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<tr>
<td></td>
<td></td>
<td>Research center</td>
<td>1 (0.3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Industry</td>
<td>2 (0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other</td>
<td>22 (5.9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
participants who answered the practice questions, 70.7% had been practicing as a PT for 6 or more years and 77.6% worked primarily in an outpatient facility (Table 1). In addition, 62.6% of the respondents have provided at least 1 year of physical therapy services in an acute sports setting, with the greatest percentages of PTs working in populations of greater than 50,000 (56.7%) (Table 1). Additional demographic information can be found in Table 1.

Twenty-seven different sports were covered by the responding PTs; individuals could respond to multiple sports in which they provide coverage. The most frequently reported covered sports were HS football (37.8% of study participants), boys HS basketball (31.4%), girls HS basketball (28.5%), boys HS soccer (27.0%), girls HS soccer (26.5%), boys HS baseball (24.2%), boys HS track/field (22.9%), girls HS track/field (22.4%), and girls HS volleyball (20.8%). Over 75.0% of the respondents felt “prepared” or “somewhat prepared” to provide immediate care in 13 of the 16 categories of injuries or medical conditions presented, except seizures (66.9%), spinal cord injuries (72.7%), and internal organ injuries (56.7%). See Table 3 for additional response percentages. The majority of the respondents (75.7%) “strongly agreed” or “agreed” they were knowledgeable regarding provision of first aid care.

The PTs’ responses to each case scenario, as well as the athlete level and game situation, associated with each scenario can be found in Table 4. Greater than 75.0% of all participants gave “appropriate” or “overly cautious” responses to 11 out of 17 case scenarios. When analyzing the relationship between the PTs’ perceived level of preparedness for various sports injuries and the “appropriate” responses of the corresponding case scenarios, results of the Spearman Rho correlation indicated minimal to no relationships \( (r < .250) \). See Table 5 for additional information.

<table>
<thead>
<tr>
<th>Table 1. Demographic information. (Continued)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Years of Providing Sports Physical Therapy in Clinical Setting (n=365)</strong></td>
</tr>
<tr>
<td>Never</td>
</tr>
<tr>
<td>&lt; 1</td>
</tr>
<tr>
<td>1-3</td>
</tr>
<tr>
<td>4-5</td>
</tr>
<tr>
<td>6-10</td>
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<td>11-15</td>
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<tr>
<td>16-20</td>
</tr>
<tr>
<td>21-30</td>
</tr>
<tr>
<td>31+</td>
</tr>
<tr>
<td><strong>Hospital in Town Providing Acute Physical Therapy (n=242)</strong></td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td><strong>Distance to nearest hospital (n=76)</strong></td>
</tr>
<tr>
<td>5-15 miles</td>
</tr>
<tr>
<td>6-30 miles</td>
</tr>
<tr>
<td>31-45 miles</td>
</tr>
<tr>
<td><strong>Direct Access in State (n=366)</strong></td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>Yes, but limited</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>I don’t know</td>
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<tr>
<td><strong>Compensated for Acute Sports Physical Therapy Services (n=233)</strong></td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
</tbody>
</table>

*Each “population” response was a separate question. Participants answer each question. Only the actual responses are reported.*
The results of chi-square analysis for “appropriate” case decisions only revealed a significant difference for the diabetes (χ² = 32.251, P = .009) and internal organ cases (χ² = 21.445, P = .006) based on years of providing acute sports coverage. For the diabetes case, those who had 11-15 or 16-20 years of experience providing care in an acute environment gave “appropriate” responses 100.0% of the time. Those who never provided acute sports physical therapy care, provided less than 1 year, and provided over 31 years of acute sports physical therapy care services gave an “appropriate” answer 80.0% or less (72.7% and 77.8% “appropriate” responses, respectively). The internal organ case was answered appropriately 80.0% or less of the time for all experience groups except the 11-15 (100.0% “appropriate”), 16-20 (84.6%), and 21-30 (90.9%) years of providing acute sports physical therapy. In addition, analysis regarding “appropriate” case decisions revealed a significant difference for asthma (χ² = 26.675, P = .000), neck injury (χ² = 11.380, P = .010), heat stroke (χ² = 15.410, P = .001), and internal organ injury cases (χ² = 27.062, P = .000) based on certifications held (certified as ATC, paramedic or EMT, first or emergency responder, or none of the 4 certifications). For example, 92.7% of ATCs, 93.7% of emergency responders, and 90.2% of PTs without 1 of these certifications gave “appropriate” responses to the asthma question, in comparison to 71.4% of paramedic/EMTs. For the neck injury question, only 54.9% of those who did not hold a certification and 58.7% of emergency responders, compared to 75.0% of ATCs and 71.4% of paramedic/EMTs, answered the neck injury question appropriately. Individuals who did not possess 1 of the 4 certifications required to sit for the SCS exam had significantly lower percentages of “appropriate” answers for heat stroke and internal organ injuries (75.3%, 67.0%), compared to ATCs (87.5%, 92.6%), paramedic/EMTs (100.0%, 100.0%), and emergency responders (93.7%, 82.3%).

The results of chi-square analysis indicated a significant difference existed in the appropriateness of case decisions based on the level of the athlete (χ² = 13.078,
An “appropriate” decision was made 75.3% of the time with starting athletes, compared to 79.3% of the time with non-starting athletes. See Table 6 for details. Results of chi-square analysis revealed significant differences in the appropriateness of the case decisions based on the game situation ($\chi^2 = 25.537$, $P = .000$). An “appropriate” decision was made in 74.1% of the time in important game situations, compared to 79.4% in non-important game situations. See Table 6 for details.

**DISCUSSION**

The majority of respondents felt “prepared” or “somewhat prepared” to provide immediate care for all conditions listed, with internal organ injuries (56.7%) having the lowest percentage of respondents who felt “prepared” or “somewhat prepared.” When it comes to treating acute sports injuries, the majority of PTs perceived themselves as having the knowledge and training to treat athletic injuries involving acute musculoskeletal injuries. For injuries that may become a medical emergency, PTs perceived themselves as being less prepared to handle these situations. Yet, at least 75.0% of the respondents made “appropriate” decisions in 11 cases related to dehydration, asthma, cardiac arrest, concussion, diabetes, fracture, heat stroke, ankle sprain, eye injury, and internal organ injury. The cases with the highest amount of “inappropriate” decisions included dislocation (51.7% “inappropriate”) and second concussion (49.3%). In all of the situations in which less than

<table>
<thead>
<tr>
<th>Condition</th>
<th>Prepared n (%)</th>
<th>Somewhat Prepared n (%)</th>
<th>Neutral n (%)</th>
<th>Somewhat Unprepared n (%)</th>
<th>Not Prepared n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concussions (n=358)</td>
<td>174 (48.6)</td>
<td>130 (36.3)</td>
<td>20 (5.6)</td>
<td>28 (7.8)</td>
<td>6 (1.7)</td>
</tr>
<tr>
<td>Dislocations (n=354)</td>
<td>198 (55.9)</td>
<td>106 (29.9)</td>
<td>16 (4.5)</td>
<td>27 (7.6)</td>
<td>7 (2.0)</td>
</tr>
<tr>
<td>Fatigue/Dehydration</td>
<td>202 (56.4)</td>
<td>116 (32.4)</td>
<td>22 (6.1)</td>
<td>15 (4.2)</td>
<td>3 (0.8)</td>
</tr>
<tr>
<td>Fractures (n=357)</td>
<td>208 (58.3)</td>
<td>105 (29.4)</td>
<td>21 (5.9)</td>
<td>15 (4.2)</td>
<td>8 (2.2)</td>
</tr>
<tr>
<td>Open Wounds (n=356)</td>
<td>205 (57.6)</td>
<td>95 (26.7)</td>
<td>29 (8.1)</td>
<td>17 (4.8)</td>
<td>10 (2.8)</td>
</tr>
<tr>
<td>Sprains (n=357)</td>
<td>322 (90.2)</td>
<td>28 (7.7)</td>
<td>4 (1.1)</td>
<td>0 (0.0)</td>
<td>3 (0.8)</td>
</tr>
<tr>
<td>Strains (n=358)</td>
<td>324 (90.5)</td>
<td>27 (7.5)</td>
<td>4 (1.1)</td>
<td>1 (0.3)</td>
<td>2 (0.6)</td>
</tr>
<tr>
<td>Asthma Attacks</td>
<td>118 (33.1)</td>
<td>160 (44.9)</td>
<td>41 (11.5)</td>
<td>30 (8.4)</td>
<td>7 (2.0)</td>
</tr>
<tr>
<td>Cardiac Arrest</td>
<td>167 (46.6)</td>
<td>126 (35.2)</td>
<td>35 (9.8)</td>
<td>23 (6.4)</td>
<td>7 (2.0)</td>
</tr>
<tr>
<td>Head Injury (n=355)</td>
<td>150 (42.3)</td>
<td>132 (37.2)</td>
<td>34 (9.6)</td>
<td>25 (7.0)</td>
<td>14 (3.9)</td>
</tr>
<tr>
<td>Heat Stroke (n=356)</td>
<td>136 (38.2)</td>
<td>145 (40.7)</td>
<td>40 (11.2)</td>
<td>26 (7.3)</td>
<td>9 (2.5)</td>
</tr>
<tr>
<td>Neck Injuries (n=358)</td>
<td>191 (53.4)</td>
<td>110 (30.7)</td>
<td>32 (8.9)</td>
<td>14 (3.9)</td>
<td>11 (3.1)</td>
</tr>
<tr>
<td>Seizures (n=357)</td>
<td>120 (33.6)</td>
<td>119 (33.3)</td>
<td>76 (21.3)</td>
<td>32 (9.0)</td>
<td>10 (2.8)</td>
</tr>
<tr>
<td>Spinal Cord (n=358)</td>
<td>132 (36.9)</td>
<td>128 (35.8)</td>
<td>44 (12.3)</td>
<td>33 (9.2)</td>
<td>21 (5.9)</td>
</tr>
<tr>
<td>Diabetes (n=358)</td>
<td>116 (32.4)</td>
<td>154 (43.0)</td>
<td>48 (13.4)</td>
<td>33 (9.2)</td>
<td>7 (2.0)</td>
</tr>
<tr>
<td>Internal Organs</td>
<td>67 (19.3)</td>
<td>130 (37.4)</td>
<td>72 (20.7)</td>
<td>55 (15.8)</td>
<td>24 (6.9)</td>
</tr>
</tbody>
</table>
75% of responding PTs did not answer the case “appropriately,” the majority of PTs felt at least “somewhat prepared” to handle the injury.

The areas in which PTs provided a higher percentage of “inappropriate” responses may be due to a lack of education and/or experience in recognizing and treating such severe acute injuries, the impact of the present game situation (important vs. non-important), the impact of the level of the athlete (starter vs. non-starter), and/or how the cases were perceived. Only 2 conditions had significantly different percentages of “appropriate” answers based on years of providing sports physical therapy in acute settings – diabetic condition and internal organ injury. For the diabetes case, those who had 11-20 years of experience providing care in an acute environment gave “appropriate” responses more often than those with less than 1 year or greater than 31 years of providing acute sports physical therapy services. Only those who provided 11-30 years of acute sports physical therapy services answered the internal organ case appropriately greater than 80.0% of the time.

Table 4. Responses to the 17 case scenario questions.

<table>
<thead>
<tr>
<th>Question &amp; Scenario</th>
<th>Hold Out &amp; Refer n (%)</th>
<th>Hold Out &amp; Monitor n (%)</th>
<th>Return &amp; Monitor n (%)</th>
<th>Return &amp; Not Monitor n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Dehydration (n=389) S, NC</td>
<td>323 (83.0)* A</td>
<td>65 (16.7)</td>
<td>1 (0.3)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>2 Asthma (n=388) S, C</td>
<td>3 (0.8) O</td>
<td>26 (6.7) O</td>
<td>349 (89.9)* A</td>
<td>10 (2.6)</td>
</tr>
<tr>
<td>3 Cardiac Arrest (n=388)</td>
<td>303 (78.1)* A</td>
<td>80 (20.6)</td>
<td>4 (1.0)</td>
<td>1 (0.3)</td>
</tr>
<tr>
<td>4 1st Concussion (n=387) S, C</td>
<td>92 (23.8) A</td>
<td>293 (75.7)* A</td>
<td>2 (0.5)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>5 Neck Injury (n=388) NS, NC</td>
<td>234 (60.3)* A</td>
<td>126 (32.5)</td>
<td>26 (6.7)</td>
<td>2 (0.5)</td>
</tr>
<tr>
<td>6 Diabetes (n=387) S, NC</td>
<td>1 (0.3) O</td>
<td>12 (3.1) O</td>
<td>328 (84.8)* A</td>
<td>46 (11.9)</td>
</tr>
<tr>
<td>7 Fracture (n=389) NS, NC</td>
<td>238 (61.2) A</td>
<td>140 (36.0)* A</td>
<td>11 (2.8)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>8 Spinal Cord Injury (n=387) S, C</td>
<td>243 (62.8)* A</td>
<td>136 (35.1)</td>
<td>8 (2.1)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>9 Head Injury (n=388) S, NC</td>
<td>287 (73.8)* A</td>
<td>92 (23.7)</td>
<td>9 (2.3)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>10 Knee Sprain (n=388) NS, NC</td>
<td>3 (0.8) O</td>
<td>17 (4.4) O</td>
<td>184 (47.4)* A</td>
<td>184 (47.4)</td>
</tr>
<tr>
<td>11 2nd Concussion (n=385) S, C</td>
<td>17 (4.4) A</td>
<td>178 (46.2)* A</td>
<td>186 (48.3)</td>
<td>4 (1.0)</td>
</tr>
<tr>
<td>12 Dislocation (n=383) S, C</td>
<td>16 (4.2) A</td>
<td>169 (44.1)* A</td>
<td>196 (51.2)</td>
<td>2 (0.5)</td>
</tr>
<tr>
<td>13 Heat Exhaustion (n=380) NS, NC</td>
<td>41 (10.8) A</td>
<td>324 (85.3)* A</td>
<td>15 (3.9)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>14 Heat Stroke (n=380) S, C</td>
<td>314 (82.6)* A</td>
<td>64 (16.8)</td>
<td>2 (0.5)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>15 Ankle Sprain (n=378) NS, NC</td>
<td>0 (0.0) O</td>
<td>77 (20.4) A</td>
<td>275 (72.8)* A</td>
<td>26 (6.9)</td>
</tr>
<tr>
<td>16 Eye Injury (n=360) S, NC</td>
<td>298 (82.8)* A</td>
<td>60 (16.7)</td>
<td>2 (0.6)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>17 Internal Organ (n=374) S, C</td>
<td>288 (77.0)* A</td>
<td>81 (21.7)</td>
<td>5 (1.3)</td>
<td>0 (0.0)</td>
</tr>
</tbody>
</table>

S- Starter, NS- Non-Starter, NC- Non-Competition/Conference Game, C- Competition/Conference Game
*A- Most appropriate answer, A- Appropriate, I- Inappropriate, O- Overly Cautious
It also should be noted that the percentage of “appropriate” answers to certain conditions were significantly different between individuals with the different credentials required to sit for the SCS examination. For neck injuries, heat stroke, and internal organ injuries, individuals without an ATC, paramedic/EMT, or first responder certification had lower percentages of “appropriate” responses. These results correspond to those reported by both Childs and colleagues and Jette et al. Children and colleagues found that licensed PTs who were board certified as a SCS or as an orthopaedic certified specialist (OCS) achieved higher scores and pass-

<table>
<thead>
<tr>
<th>Question</th>
<th>Decision</th>
<th>Prepared n (%)</th>
<th>Somewhat Prepared n (%)</th>
<th>Neutral n (%)</th>
<th>Somewhat Unprepared n (%)</th>
<th>Not Prepared n (%)</th>
<th>Spearman</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 vs Dehydration (n=358)</td>
<td>A</td>
<td>162 (55.1)</td>
<td>101 (34.4)</td>
<td>16 (5.4)</td>
<td>12 (4.1)</td>
<td>3 (1.0)</td>
<td>-.040</td>
<td>.453</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>40 (62.5)</td>
<td>15 (23.4)</td>
<td>6 (9.4)</td>
<td>3 (4.7)</td>
<td>0 (0.0)</td>
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<td></td>
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<tr>
<td>Q2 vs Asthma (n=356)</td>
<td>A</td>
<td>107 (32.9)</td>
<td>150 (46.2)</td>
<td>35 (10.8)</td>
<td>28 (8.6)</td>
<td>5 (1.5)</td>
<td>.029</td>
<td>.582</td>
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<td></td>
<td>I</td>
<td>4 (50.0)</td>
<td>1 (12.5)</td>
<td>1 (12.5)</td>
<td>1 (12.5)</td>
<td>1 (12.5)</td>
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<tr>
<td></td>
<td>OC</td>
<td>7 (30.4)</td>
<td>9 (39.1)</td>
<td>5 (21.7)</td>
<td>1 (4.3)</td>
<td>1 (4.3)</td>
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<tr>
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<td>A</td>
<td>134 (48.6)</td>
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<td>.055</td>
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<td>34 (42.0)</td>
<td>10 (12.3)</td>
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<td>1 (1.2)</td>
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<tr>
<td>Q4 vs Concussion (n=357)</td>
<td>A</td>
<td>171 (48.2)</td>
<td>130 (36.6)</td>
<td>20 (5.6)</td>
<td>28 (7.9)</td>
<td>6 (1.7)</td>
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<tr>
<td></td>
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<td>Q5 vs Neck Injury (n=357)</td>
<td>A</td>
<td>127 (57.7)</td>
<td>63 (28.6)</td>
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<td>I</td>
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<td>47 (34.3)</td>
<td>14 (10.2)</td>
<td>6 (4.4)</td>
<td>7 (5.1)</td>
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<td>Q6 vs Diabetes (n=357)</td>
<td>A</td>
<td>102 (33.4)</td>
<td>134 (43.9)</td>
<td>38 (12.5)</td>
<td>27 (8.9)</td>
<td>4 (1.3)</td>
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<td>.045</td>
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<td></td>
<td>I</td>
<td>11 (26.2)</td>
<td>15 (35.7)</td>
<td>9 (21.4)</td>
<td>5 (11.9)</td>
<td>2 (4.8)</td>
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</tr>
<tr>
<td></td>
<td>OC</td>
<td>2 (20.0)</td>
<td>5 (50.0)</td>
<td>1 (10.0)</td>
<td>1 (10.0)</td>
<td>1 (10.0)</td>
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<td>Q7 vs Fracture (n=357)</td>
<td>A</td>
<td>201 (57.9)</td>
<td>103 (29.7)</td>
<td>20 (5.8)</td>
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<td>8 (2.3)</td>
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<tr>
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<td>Q8 vs SCI (n=357)</td>
<td>A</td>
<td>88 (40.6)</td>
<td>80 (36.9)</td>
<td>22 (10.1)</td>
<td>14 (6.5)</td>
<td>13 (6.0)</td>
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<td></td>
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<td>22 (15.7)</td>
<td>19 (13.6)</td>
<td>8 (5.7)</td>
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<td>Q9 vs Head Injury (n=355)</td>
<td>A</td>
<td>119 (44.9)</td>
<td>101 (38.1)</td>
<td>22 (8.3)</td>
<td>17 (6.4)</td>
<td>6 (2.3)</td>
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<td></td>
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<td>12 (13.3)</td>
<td>8 (8.9)</td>
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<tr>
<td>Q10 vs Sprain (n=357)</td>
<td>A</td>
<td>157 (94.0)</td>
<td>5 (3.0)</td>
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<td>.038</td>
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<td></td>
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<td>150 (86.7)</td>
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<tr>
<td></td>
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<td>0 (0.0)</td>
<td>0 (0.0)</td>
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<tr>
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<td>A</td>
<td>96 (52.5)</td>
<td>62 (33.9)</td>
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<td>9 (4.9)</td>
<td>4 (2.2)</td>
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<td>77 (44.3)</td>
<td>68 (39.1)</td>
<td>8 (4.6)</td>
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<td>A</td>
<td>87 (51.8)</td>
<td>59 (35.1)</td>
<td>6 (3.6)</td>
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<td>.237</td>
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<tr>
<td></td>
<td>I</td>
<td>111 (60.0)</td>
<td>47 (25.4)</td>
<td>10 (5.4)</td>
<td>13 (7.0)</td>
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<td>Q13 vs Heat Stroke (n=352)</td>
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<td>136 (39.9)</td>
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<td>6 (54.5)</td>
<td>0 (0.0)</td>
<td>2 (18.2)</td>
<td>1 (9.1)</td>
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<tr>
<td>Q14 vs Heat stroke (n=356)</td>
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<td>122 (41.6)</td>
<td>112 (38.2)</td>
<td>34 (11.6)</td>
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<td>6 (2.0)</td>
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<td>.009</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>14 (42.2)</td>
<td>33 (52.4)</td>
<td>6 (9.5)</td>
<td>7 (11.1)</td>
<td>3 (4.8)</td>
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<tr>
<td>Q15 vs Sprain (n=356)</td>
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<td>298 (90.0)</td>
<td>25 (7.6)</td>
<td>4 (1.2)</td>
<td>3 (0.9)</td>
<td>1 (0.3)</td>
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<td>.727</td>
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<tr>
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<tr>
<td>Q16 vs Head Injury (n=328)</td>
<td>A</td>
<td>113 (41.9)</td>
<td>99 (36.7)</td>
<td>28 (10.4)</td>
<td>18 (6.7)</td>
<td>12 (4.4)</td>
<td>.001</td>
<td>.989</td>
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<td></td>
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<td>5 (8.6)</td>
<td>5 (8.6)</td>
<td>1 (1.7)</td>
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<td></td>
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<td>Q17 vs Internal Organ (n=344)</td>
<td>I</td>
<td>61 (22.8)</td>
<td>100 (37.5)</td>
<td>48 (18.0)</td>
<td>39 (14.6)</td>
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<td>.004</td>
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<td>16 (20.8)</td>
<td>5 (6.5)</td>
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</table>

A=Appropriate; I=Inappropriate; OC=Overly Cautious
ing rates on an examination assessing knowledge in managing musculoskeletal conditions than PTs who were not board certified. Jette et al. reported that PTs who obtained an OCS were almost twice as likely to make correct decisions for 12 hypothetical critical medical and musculoskeletal conditions hypothetical case.

Thus, individuals who do not currently possess one of the possible certifications required to take the SCS exam, but who desire to provide on-the-field sports physical therapy, may want to participate in continuing education that includes medical condition recognition and management and/or be mentored by a PT who is also credentialed as an ATC, paramedic, EMT, or emergency responder. Even if individuals have one of the mentioned certifications, they may want to take additional courses and/or be mentored by someone with greater than 11 years of experience in acute sports physical therapy. Although the most commonly covered sports by responding PTs were HS boys football, boys/girls basketball, boys/girls soccer, boys baseball, boys/girls track/field, and girls volleyball, it is important that PTs recognize the importance of being prepared to cover all types of sports, not just those that are more popular than others. To do such, PTs need to know the characteristics of typical injuries associated with each sport, as well as the role and position of each player on the team, as injuries typically correspond with position of play.

Regarding preparedness to handle various acute injuries and medical conditions, as well as the ability to make “appropriate” decisions for various acute sports condition cases, the PTs in the current study had higher overall scores as compared to the HS coaches who responded to the scenarios presented in the study by Cross et al. For the 16 medical conditions listed, a higher percentage of PTs reported feeling “prepared” or “somewhat prepared” than coaches. Coaches only noted 5 medical conditions, while PTs reported 13 conditions, in which greater than 75% felt “prepared” or “somewhat prepared” to handle. Part of this may be related to the fact that 54% of the coaches were certified in CPR, 50.0% in first aid, and 7.4% as an ATC, paramedic, EMT, or first responder, compared to 87.1%, 55.5%, and 48.3%, respectively, of PTs in this study who stated that they were certified in these areas. Cases in which 75.0% or more of PTs gave “appropriate” or “overly cautious” responses, but coaches gave less than 75.0%, included heat stroke (82.6% of PTs, 73.4% of coaches), eye injury (82.8%, 45.7%), and internal organ injury (77.0%, 57.0%). In contrast, 81.5% of coaches gave “appropriate” responses (“hold out and refer”) to the case involving a potential spinal cord injury, compared to only 62.8% of PTs; PTs were more likely to “hold out and monitor.”

Adequate acute sports injury knowledge is not the only factor when making “appropriate” or “inappropriate” decisions on holding out the athlete or returning the athlete to the competition. As stated previously, the level of the athlete (starter or non-starter) and the game situation (important game or non-important game) can drastically effect the decisions of coaches regarding whether or not an athlete is allowed to return to the competition. Coaches made “appropriate” decisions 68.9% of the time when the injury occurred with a starting athlete, compared to 79.3% when a non-starter was injured, whereas PTs made the “appropriate” decision 75.3% of the time when injuries involved starters, compared to 79.3% of the time when the injury involved a non-starter. During important games, coaches made “appropriate” decisions 66.5% of the time, compared to 76.6% during non-important games, whereas during important games, PTs made “appropriate” decisions 74.1% of time during important games, compared to 79.4%
during non-important games. Thus, PTs tended to make “appropriate” decisions more often than the coaches, regardless of the level of athlete or game scenario, which may support the idea that a nonbiased, properly trained medical professional should be responsible for the return to sport decision making, instead of a coach. However, it must be noted though that a significant difference did exist for both PTs and coaches\(^1\) with regard to “appropriate” responses based on the level of the athlete and the game situation. Due to the fact that previous studies have noted a lack of medical personnel at HS athletic practices and games,\(^8\) especially for schools located in rural areas,\(^9\) PTs who are willing to provide pro bono acute sports physical therapy services to schools, who cannot afford to employ an ATC or other medical provider, may help to reduce the disparity in coverage of HS practices and competitions that currently exists.

**Limitations**

Generalization of the study results to all PTs is not appropriate for multiple reasons. First, this survey was only distributed to PTs who were members of the SPTS with valid e-mail addresses. Over 8.2% PTs who were members of the SPTS in the Fall of 2009 did not receive an invitation to participate in the study as they did not have a valid e-mail address listed with the SPTS. This is compounded further by the fact that PTs who are members of the SPTS make up a small percentage of all PTs in the United States. Second, the low response rate further limits the generalizability of the study. The low response rate may be partly related to the length of the survey; similarly, only 10.2% of coaches in South Dakota took the time to complete the original survey.\(^13\) The authors of the current study tried to minimize the low response rate by sending out an e-mail reminder and by giving participants the opportunity to be entered into a drawing for a gift card. Additionally, the demographics of the PTs who participated in the study did not fully match the membership profile of the SPTS. The SPTS consists of 60.5% male and 39.5% female PTs (Robert Manske, DPT, e-mail communication, August 5, 2011), whereas respondents to this study were 66.0% male and 34.0% female. Additionally, 17.5% of responding PTs were an SCS and 12.6% were an OCS, compared to 9.5% and 13.5%, respectively, of all of the PTs in the SPTS (Robert Manske, DPT, e-mail communication, August 5, 2011). Based on the findings in the studies of Childs and colleagues\(^29\) and Jette et al,\(^30\) as a higher percentage of certified specialists participated in this study, in comparison to those with a SCS and/or an OCS who are members of the SPTS (the population), it could be argued that a higher percentage of “appropriate” answers may have been given to the cases than what the population of the SPTS would have given.

It must also be noted that since the e-mail distributed to the PTs included an anonymous link to the survey, the authors are unable to determine who actually took the survey (ATCs, student PTs, etc.). The e-mail distribution list included all members of the SPTS, not just PTs. Even though the cover letter stated that the survey was for PTs only, other individuals may have responded. In addition, whether or not the link was forwarded to individuals who were not members of both the APTA and/or SPTS could not be controlled. Furthermore, there was no control over how many times a PT was able to access the link and take the survey, which could have led to the same individual taking the survey multiple times.

Finally, even though this study used the same 16 medical conditions and 17 case studies that were used in the previous study by Cross et al,\(^13\) comparisons regarding perceived level of preparedness and appropriate acute medical condition decision making cannot be made between PTs and coaches nationally, as the study by Cross et al\(^13\) was only conducted with South Dakota HS head coaches and the current study assessed PTs who were members of the SPTS of the APTA.

**CONCLUSIONS**

Over 75.0% of responding PTs reported feeling “prepared” or “somewhat prepared” to provide immediate care for 13 out of 16 acute athletic injuries and medical conditions. In addition, over 75.0% of responding PTs made “appropriate” decisions for 11 of the 17 acute injury and medical condition case scenarios. Years of experience providing acute sports physical therapy and the attainment of a certification necessary to sit for the SCS exam\(^24\) seem to have a positive effect on a PT’s ability to make “appropriate” decisions related to the management of various acute medical conditions not often seen in a traditional
outpatient physical therapy clinic environment. Overall, responding PTs felt more prepared and demonstrated better decision making regarding acute sports related injuries than head coaches in South Dakota. However, those PTs who plan on assisting at sporting events, and decreasing the disparity that exists in relation to the lack of health care providers available at HS sporting practices and events, should consider participating in additional training/continuing education, such as what is taught in the ARC Emergency Response Course, and/or obtain mentorship in this realm of physical therapy practice. Future research could include utilizing the case scenarios in a pre-test/post-test format to assess participant learning from various continuing education courses, including the ARC Emergency Response Course. Additional investigations could also include utilizing the survey by Cross et al to determine the level of perceived preparedness, as well as appropriateness of decision making for managing acute injury and medical conditions, among other health care providers and coaches, nationally.

ACKNOWLEDGEMENTS

We would like to thank Dr. Robert Manske, Tammy Jackson, and the rest of the Executive Board of the SPTS of the APTA for supporting our project by providing e-mail addresses and demographic information of those PTs who were members of the SPTS. We would also like to thank Dr. Danny Smith for his help and encouragement throughout the process, as well as all the PTs who volunteered their time to complete the survey and provide feedback.

REFERENCES


ABSTRACT

Objective: To describe sledge hockey injury patterns, safety issues and to develop potential injury prevention strategies.

Design: Pilot survey study of international sledge hockey professionals, including trainers, physiotherapists, physicians, coaches and/or general managers.

Setting: Personal encounter or online correspondence.

Respondents: Sledge hockey professionals; a total of 10 respondents from the 5 top-ranked international teams recruited by personal encounter or online correspondence.

Main Outcome Measurements: Descriptive Data reports on sledge athlete injury characteristics, quality of rules and enforcement, player equipment, challenges in the medical management during competition, and overall safety.

Results: Muscle strains and concussions were identified as common, and injuries were reported to affect the upper body more frequently than the lower body. Overuse and body checking were predominant injury mechanisms. Safety concerns included excessive elbowing, inexperienced refereeing and inadequate equipment standards.

Conclusions: This paper is the first publication primarily focused on sledge hockey injury and safety. This information provides unique opportunity for the consideration of implementation and evaluation of safety strategies. Safety interventions could include improved hand protection, cut-resistant materials in high-risk areas, increased vigilance to reduce intentional head-contact, lowered rink boards and modified bathroom floor surfacing.

Key words: Disabled athlete, Paralympic, sledge hockey
INTRODUCTION

Sledge hockey is a modified version of regular ice hockey with similar equipment, rules, strategy, degree of player contact, and level of competition. Ice Sledge Hockey is practiced by athletes in 15 countries and is governed by the IPC with co-ordination by the IPC Ice Sledge Hockey Technical Committee. It follows the rules of the International Ice Hockey Federation (IIHF) with modifications. The sport targets athletes with a physical disability, typically affecting the lower body. A sledge (derived from the term ‘sled’) is used as an adaptive device whereby the player remains seated during competition.

The sled is supported on two steel hockey blades (about 3 mm in thickness) and is reinforced by a frame and front skidder.1 Straps help secure a player’s feet, ankles, knees and hips while seated. (Figure 1) Each player carries two sticks, one in each hand, both of which can be used for puck handling and player movement. The sticks are made of wood, aluminum or titanium and are subject to restrictions on length and sharpness. During propulsion, the players use the ‘toothed’ proximal end for traction while a ‘bladed’ distal end is used for shooting and passing the puck. The remaining equipment is essentially standard hockey gear, excluding skates, as standard footwear is used by sledge hockey players. The players rely on their upper body to propel themselves across the ice surface and can gain enough speed and momentum for fierce body checking.1 (Figure 2)

Relatively little is known about the injury patterns among sledge hockey athletes. Literature searches in the Ovid and Pubmed databases for the keyword “sledge hockey”, “sledge disabled” and “sledge paralympic” research published in English rendered only 1 paper. This study by Webborn et al. reviewed injury patterns at the 2002 Salt Lake City Winter Paralympic Games with respect to injury type, acuity, body location, gender and inciting sport. Injury data was collected as athletes presented to a common medical polyclinic in the Paralympic Village. Sledge hockey had the highest rate of injury at 14% (12/88 athletes) versus alpine skiing at 12% (24/194), with acute trauma the major precipitant.2 The types of trauma causing injury in sledge hockey have not been well described, and it remains unclear as to which aspects of the sledge hockey sport are most dangerous. The authors highlighted the need for further study as “several or more of the injuries were potentially preventable”.2

There is an increasing need to advance sports medicine for athletes with disability.3 First, the growing demand for resources and accessibility has prompted new equipment, venues for competition and an evolution of adaptive sports.4 Published figures on Paralympic sport participation suggest an ongoing trend of increased participation by athletes and representative countries.5 Second, sport participation in this group is associated with higher levels of self-esteem, improved physical and emotional functioning, social recognition and a strong sense of identity.6 Finally, further disability resulting from a sports injury can be associated with significant patient morbidity. For example, lengthy (and costly) hospitalizations could...
be avoided for preventable issues such as pressure ulcers, fragility fractures and shoulder injuries.\(^7\)

The objective of this pilot survey was to collect data from experienced professionals regarding sledge hockey injury and safety, and to identify potential injury patterns found within the sport. A secondary objective was to assess discrete components of sledge hockey (including rules, equipment design, training etc.) in order to develop suggestions for safety improvement.

**METHODS**

A novel survey was created to cover a variety of potential sledge hockey injury and safety issues. Topics and questions were generated from research strategies found within an able-bodied hockey injury publication which focused on injury type, location, specific injury and mechanism.\(^8\) Further supplemental questions were included at the discretion of the researchers for purposes of exploring the general topic sledge injury and safety. The survey consisted of three core sections: participant characteristics, injury description and safety questions. The survey in its entirety has been included in Appendix A. Two versions were used, one online, one printed. The online version was established through the surveymonkey.com website and matched the printed format. Approval was obtained from the Vancouver Coastal Health and University of British Columbia review boards.

First, the top five international sledge hockey teams were selected based on their most recent finish at a IPC Sledge Hockey World Championships. General Managers from these teams were provided with the study details with the assistance of Hockey Canada. Permission was granted by the general managers for the researchers to approach the team staff. Two persons from each team, including the trainer, physiotherapist, physician, coach and/or general manager were then asked to participate. If there were more than two willing respondents from each team, then preference was given to medical professionals, followed by those with the most sledge hockey experience. The authors decided to use only two persons from each team to improve the likelihood of having an even sample of survey respondents per team. The consent and survey process took place via direct personal encounter or through the online survey engine, depending on preference of the participant. Provisions for language translation were provided as needed. Further information about the respondents, including their credentials, language and representative teams have been omitted to ensure confidentiality.

Quantitative data was obtained from respondents by their ranking of injuries using structured lists derived from research in able-bodied athletes (8). Respondents ranked injuries (defined as ‘any injury that caused an athlete to stop, limit or modify participation for 1 day or more’) numerically based on perceived frequency with respect to type, location, specific injury and mechanism.\(^8\) For example, each participant was asked to rank the four most common injury types based on their personal experience. They were provided with a list which included the items bleeding / cut, concussion, contusion, dislocation, fracture, ligament sprain and muscle sprain. The item perceived to be most frequent by the respondent were ranked as 1, and subsequent rankings were 2 through 4. Since each question provided a list with several options, certain items were therefore left unranked. A novel scoring system was developed to provide a graphic representation of qualitative responses. A 1st ranking received 4 points, a 2nd ranking received 3 points, a 3rd ranking received 2 points and a 4th ranking received 1 point. Items that were not ranked in the lists received zero points. The summated score of each item was obtained based on answers from the 10 respondents. Results were downloaded from the online survey engine and converted to a spreadsheet format. Since the data was quantified from subjective rankings, the authors chose not to apply any statistics and instead reported results in a descriptive context.

Further qualitative data was obtained through analysis of optional subjective responses from open-ended survey questions directed towards injury characteristics, improving medical care, treatment challenges, rule enforcement, equipment modification and opportunity for free comment. All comments were analyzed for content then reported in an abbreviated, listed format. No exclusions were made. Suggestions for safety interventions were drawn from both the quantitative and qualitative data obtained during the study.
RESULTS
Two persons from each of the top-five ranked international sledge hockey teams participated in the survey, for a total of 10 respondents. Participation rate was 100% amongst those who were asked to complete the survey by the general manager or the researchers. All persons completed the pertinent 8 questions pertaining to the 3 core sections summarized in Tables 1-3. Subjects with a range of professional backgrounds represented teams from 3 different continents. A summary of responses

<table>
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<td></td>
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<td>Team Location</td>
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<th>Table 3. Qualitative Responses summary.</th>
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from multiple choice questions pertaining to the respondent's profession, years experience and team location are provided in Table 1.

Table 2 presents a summary of all data related to injuries, including location, type, and mechanism of injury, as well as details for injuries that were not match related.

The cumulative score for rankings of injury type, location, specific injury and mechanism are provided in Figures 3 to 6. As described earlier, the score along the vertical axis was obtained by adding up points from the 10 respondents for each item ranked. Highly ranked items (perceived as frequent) received more points than lower ranked or unranked options. Thus, a higher scoring item is suggestive of an item being more frequent compared to a lower scoring item.

Dislocations (ranked as a top 4 option by 2/10 respondents) and fractures (4/10) were regarded as less common compared to other injury types such as a muscle strain (8/10) and concussion (8/10).

Figure 3. Most frequent injury types based on summated scores from respondent rankings.

Figure 4. Most frequent injury locations based on summated scores from respondent rankings.

Figure 5. Most frequent specific injuries based on summated scores from respondent rankings.

Figure 6. Most frequent injury mechanisms based on summated scores from respondent rankings.

Dislocations (ranked as a top 4 option by 2/10 respondents) and fractures (4/10) were regarded as less common compared to other injury types such as a muscle strain (8/10) and concussion (8/10).

Highly-ranked specific injuries included shoulder sprains (10/10), concussions (6/10) and chest contusion / rib fractures (10/10).

Body checking (9/10) and overuse injury (7/8) were viewed as the most common injury mechanisms.

Responses to open-ended questions were provided regarding sport safety and injury prevention, including concerns of excessive elbowing, inexperienced refereeing and inadequate equipment standards. Qualitative responses are summarized in Table 3.

**DISCUSSION**

Sledge hockey is a relatively new sport with a paucity of medical literature regarding sport injury and player
safety. This pilot study attempts to summarize opinion from the medical staff and experienced management amongst top international teams. These data suggest that sledge injuries may follow a unique pattern based on the sledge's adapted equipment and nature of play.

Researchers are presented with a number of challenges that have limited the advancement of sports medicine for athletes with disability. Within the sledge hockey group, each international team is comprised of athletes who could have a spinal cord injury, amputation, neuromuscular impairment or congenital anomaly. These different deficits translate into distinct movement patterns, a variety of abilities regarding usage of core and limb musculature and a varying ability to maneuver efficiently. Factors such as seating position, player height, truncal control and total body mass may also be considered when researching injury. New adaptive sporting equipment adds further complexity, as devices are tailored to each athlete and have inherent risks and benefits. As such, research becomes challenging due to a heterogenous sample population with the resultant need for application of research outcomes to the individual player.

While regular ice hockey leagues are plentiful, research opportunity in sledge is relatively scarce outside of international competition. Reliance on the co-operation between the researchers and tournament teams is significant despite language barriers and possible competing interests. These issues may have limited the amount of sledge hockey research available to date.

Injuries to the shoulder, elbow and wrist were considered significantly more common as compared to injury in other body regions. The mechanism of player propulsion places a high demand on the upper extremity joints and musculature through a distinct pulling motion. Also, shooting the puck is restricted to one arm (as compared to two arms during most able-bodied hockey shots) with body weight transfer less feasible while positioned seated in the sled. Injury to the lower extremities was considered relatively rare. Bony or soft tissue damage to the thighs, legs or feet may still occur; however, these are less likely to limit player participation.

Contusions, ligaments sprains and muscle strains were rated relatively equal in frequency, while fractures and dislocations were considered uncommon. This injury description (pertaining to injury type) is comparable to the pattern found in another study of able bodied hockey athletes. Overuse injury and bodychecking were cited as the predominant injury mechanisms. The overuse ‘wrist tendonitis’ specially identified by half the respondents could be related to repetitive forceful wrist flexion during a player's typical shooting motion. Bodychecking is particularly dangerous in sledge hockey, since the dasherboards (designed for regular ice hockey) are commonly above the player's seated height. The bottom boards are quite rigid and much less forgiving compared to the flexible transparent shields located above.

Concussions were cited as a major concern amongst the respondents. Given that player contact is a predominant mechanism of injury in both regular ice hockey and sledge hockey, and that increased concussion rates are associated with increased body contact in regular ice hockey, the authors suspect that concussions in sledge hockey largely occur during bodychecking. A sledge athlete’s propulsion is gained almost entirely through upper body motion. Thus, the relative movement of the arms and forearms at the moment of contact during a bodycheck may be greater when compared to the same maneuver by a regular ice hockey player. The qualitative data (in Table 3) raises concerns of excessive elbowing going unnoticed by referees during player contact, perhaps in relation to this unique pattern of movement. A heightened degree of referee vigilance was recommended by a few respondents.

Concerns were raised about player's willingness to ‘admit’ concussive symptoms to the medical staff, an issue that has been raised in many other sports at a variety of levels. In the sledge group, this poses a heightened risk for a traumatic brain injury-related cognitive impairment amongst persons already dealing with a significant disability. The authors would endorse initiatives such as athlete education, targeted referee training, baseline cognitive scoring assessment, and adjustment of the dasher boards in an effort to reduce traumatic brain injury severity. A prospective evaluation of these initiatives would help to identify their effectiveness in reducing the rate of concussions.

A variety of safety concerns were provided in Table 3. Player's hands are vulnerable to lacerations and
crush injuries while positioned near the ice surface – thus more supportive material on the volar glove surfaces was recommended. Likewise, puncture wounds and/or lacerations are commonly found on a player's trunk depending on movement of the opposing player's pick end of the stick during a slash. Proper wound care then becomes important due to the presence of sweaty overlying equipment, and the possibility of altered sensation supplying the affected skin areas.

One final area of concern was described related to a hockey rink's adaptive set-up for sledge athletes. Issues with the rink's boards have already been discussed. Respondents identified inadequate floor surfacing in the showers as a contributor to two post-game player injuries. Sanitized shower seats could provide the necessary stability over the slippery surfaces for disabled athletes during self-hygiene. As a final illustration, if 17 players on a team arrive with a wheelchair or prosthetic limb, and 17 sleds are required (one unique one for each individual), then adequate space and organization is necessary in order to provide a safe environment for all the players and their equipment, along with the team staff. Overall, the rink, hallway and locker-room design should be suitably adapted.

The authors believe that the data obtained for this pilot study was through an expression of genuine interest for player safety by experienced professionals. This study's qualitative information may help guide a variety of safety interventions, which includes improved hand protection, cut-resistant materials in high-risk areas, increased vigilance to reduce intentional head-contact, modified rink boards and showering area modifications. Each item identified could be addressed with a straightforward intervention without affecting the quality of play.

LIMITATIONS AND SUGGESTIONS FOR FUTURE RESEARCH
Weaknesses of this pilot study relate to the solicitation of opinion from a group of both medical and non-medical professionals, the inability to clarify or contact a true ‘expert’ in this evolving sports medicine field, and recall bias. This study incorporated qualitative data, with unclear reliability and validity of the survey itself. Thus, this study can be only be used for the purpose of hypothesis generation. The small sample size limits the ability to assess risk factors or other epidemiologic variables. In the future, a longitudinal prospective injury surveillance study is needed to gather actual injury information for identification and study of safety initiatives.

REFERENCES
## Sledge Hockey Safety and Injury Prevention Survey

### 1. Introduction

Your participation is greatly appreciated!

Please keep in mind that by continuing on with this survey, you have given your consent to participate. You can skip a question or finish / exit the survey at any time if you wish.

Feel free to contact Dr. Jon Hawkeswood at jphawkes@interchange.ubc.ca if you have any further questions.

This brief survey should take you less than 10 minutes, but please take your time.

We hope to improve player safety through injury prevention, and your input is important!

![UBC Logo]

Please refer to the original consent form for complete research details.

### 2. Participant Description (1 of 3 sections with questions)

#### 1. What is your role with your Sledge Hockey team?

- [ ] coach
- [ ] trainer / exercise and conditioning
- [ ] physiotherapist
- [ ] physician

#### 2. Approximately how many years have you been involved with Sledge Hockey?

- [ ] 1 year (or less)
- [ ] 2 years
- [ ] 3 years
- [ ] 4 years
- [ ] 5 years or more

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Sledge Hockey Safety and Injury Prevention Survey

3. Please keep in mind your responses are anonymous. On which continent does your team reside?

☐ Europe
☐ Asia
☐ North America
☐ Other (please specify)

3. Important Information!

The next three questions will require that you:
- decide which options within the lists represent the four commonest issues.
- identify and rank those choices using the numbers 1 (most common) to 4 (least common)

Please note that four choices represent the maximum allowed, and you can include less than four if you wish.
You will be given opportunity to elaborate on any questions or problems at the end of the survey.

One important note:

Definition of injury: 'any injury that caused an athlete to stop, limit or modify participation for 1 day or more.'

4. Injury Questionnaire (2nd of 3 sections with questions)

1. From the list provide, please ESTIMATE (from your personal experience) which FOUR TYPES OF injuries are most common, by RANKING the FOUR most common:

bleeding /cut
concussion
contusion
dislocation
fracture
ligament sprain
muscle strain

2. Are there any other types of injuries you'd like to identify?
Sledge Hockey Safety and Injury Prevention Survey

3. From the list of injuries provided, please ESTIMATE (from your personal experience) which FOUR LOCATION OF injuries are most common, by RANKING on the FOUR most common:

- arm / elbow
- back
- chest / abdomen
- head / face
- hip / groin / thigh
- knee
- lower leg / ankle foot
- neck throat
- shoulder / collarbone
- wrist / hand

4. Are there any other location of injuries you’d like to identify?

5. The list below includes injuries known to occur in regular ice hockey. Which FOUR SPECIFIC INJURIES do you see as being most common during Sledge Hockey:

- concussion or knocked out
- shoulder sprain / dislocation
- knee sprain / strain
- upper extremity fracture
- groin / thigh muscle strain
- neck / back muscle strain
- chest / rib fracture / contusion
- lower extremity fracture

6. Are there any other specific injuries you'd like to identify?


Sledge Hockey Safety and Injury Prevention Survey

7. What are the most common mechanisms of injury (please rank up to four)?

- body checking (tactic to legally separate the puck carrier from the puck)
- other intentional contact (slashing, elbowing, tripping)
- incidental body contact (not body checking)
- environment (injury caused by puck, boards, net, etc. but not player body contact)
- other (please specify - this includes ‘no contact’)

5. Final section with questions (some descriptive)

Please be reminded that your confidentiality is of utmost importance to us!

1. Please indicate whether or not you have safety concerns in regards to the following (and feel free to comment):

- rules (for example, allowing body checking)
- enforcement of rules (for example, refereeing)
Sledge Hockey Safety and Injury Prevention Survey

2. Please indicate whether or not you have safety concerns in regards to the following (and feel free to comment):

- player equipment
- sled design

3. Which of the above issues are most important and why?

4. Using the space below, describe / outline any major challenges you have experienced with the acute management of sledge hockey athletes.

5. Do you have any further comment on the types or severity of injuries you have witnessed, perhaps not included in the lists provided earlier?
Sledge Hockey Safety and Injury Prevention Survey

6. Do you have any specific recommendations to improve the overall safety of the sledge hockey sport?

7. Do you have any concerns or general comments about the quality of the medical care that sledge hockey participants receive?

Thank again for your participation. Best of luck to you and your team in the future!

6. Final Thank-You

Again, your time is much appreciated.

This survey was created by Dr. J.P. Hawkeswood, a medical resident at UBC studying the specialty of Physical Medicine and Rehabilitation.

If you have any inquires regarding this survey, or would like to contact Dr. Hawkeswood for future Sledge Hockey reference, feel free to do so at:

jphawkes@interchange.ubc.ca or call (604) 803-0321

Thanks once again,

Jon

The University of British Columbia, 2009.
ABSTRACT

**Purpose:** To determine if heel height alters sagittal plane knee kinematics when landing from a forward hop or drop landing.

**Background:** Knee angles close to extension during landing are theorized to increase ACL injury risk in female athletes.

**Methods:** Fifty collegiate females performed two single-limb landing tasks while wearing heel lifts of three different sizes (0, 12 & 24 mm) attached to the bottom of a sneaker. Using an electrogoniometer, sagittal plane kinematics (initial contact [KAIC], peak flexion [KAPeak], and rate of excursion [RE]) were examined. Repeated measures ANOVAs were used to determine the influence of heel height on the dependent measures.

**Results:** Forward hop task - KAIC with 0 mm, 12 mm, and 24 mm lifts were 8.8° ± 6.5, 9.3° ± 5.8 and 11.2° ± 7.0, respectively. Significant differences were noted between 0 and 24 mm lift (p<.001) and 12 and 24 mm lifts (p=.003), but not between the 0 and 12 mm conditions (p=.423). KAPeak with 0 mm, 12 mm, and 24 mm lifts were 47.0° ± 10.9, 48.1° ± 10.3 and 48.8° ± 9.7, respectively. A significant difference was noted between 0 and 24 mm lift (p=.004), but not between the 0 and 12 mm or 12 and 24 mm conditions (p=.071 and p=.282, respectively). The RE decreased significantly from 212°/sec ± 52 with the 12 mm lift to 195°/sec ± 55 with the 24 mm lift (p=.004). RE did not differ from 0 to 12 or 0 to 24 mm lift conditions (p=.351 and p=.086, respectively). Jump-landing task - No significant differences were found in KAIC (p=.531), KAPeak (p=.741), or the RE (p=.190) between any of the heel lift conditions.

**Conclusions:** The addition of a 24 mm heel lift to the bottom of a sneaker significantly alters sagittal plane knee kinematics upon landing from a unilateral forward hop but not from a drop jump.

**Key Words:** ACL, heel lift, kinematics, landing

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This work was completed in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Rehabilitation Science at Duquesne University.

This study was approved by the Institutional Review Board at Duquesne University.
INTRODUCTION

It is well established that anterior cruciate ligament (ACL) injuries occur more frequently in female compared to male athletes. However, extensive research into the basis of this gender disparity continues to be inconclusive. Although many theories have been proposed, no evidence exists to overwhelmingly support any single cause for the female’s propensity towards ACL injury suggesting that the link may be multi-factorial. Furthermore, researchers have struggled to establish consistent suggestions regarding proven methods to limit or prevent these injuries.

Risk factors for sustaining ACL injuries have been categorically classified as those related to environmental, anatomical, hormonal, or biomechanical origins. There are obvious limitations in the feasibility of altering some of these risk factors. Given the ability to alter joint kinematics and muscle activity, many researchers have conducted studies that have focused on biomechanical risk factors utilized by female athletes during jumping and landing activities. Videotape analysis of ACL injuries in both genders has demonstrated that a common characteristic observed at the time of injury is a knee posture close to extension. Researchers have demonstrated that females repeatedly utilize this kinematic pattern in a variety of sport maneuvers.

The ramifications of a more extended knee posture during landing include increased electrical activity of the quadriceps, increased anterior tibio-femoral shear and increased vertical ground reaction forces. Likewise, there is a decrease in activity of the hamstrings and less sagittal plane knee joint excursion occurs throughout the movement resulting in less time to attenuate forces and moments at the joint. Each of the aforementioned compensations are thought to increase ACL injury risk.

ACL injury prevention programs have been used to favorably influence kinematic patterns during varied landing tasks in female athletes. Preventative exercise programs designed for female athletes participating in a variety of sports typically consist of plyometric activities and have demonstrated the ability to positively affect lower extremity kinematics and kinetics in laboratory settings as well as decrease injury rates on the field. However, many of these programs require a substantial time investment of 90-minutes or more several times per week, often requiring greater than six-weeks of consistent training. This time commitment may dissuade coaches and athletes from participating. Among those that do participate, the time component is apt to have negative effects on compliance, which has been demonstrated to be a substantial factor in the overall success of a program. Researchers that used training programs requiring only 15 minutes to complete found that only the most elite athletes who were consistently compliant had a decrease in injury rates, while other athletic populations or less compliant subjects saw no changes. Furthermore, the duration of the protective effects of these training programs after cessation of participation is unknown.

A prevention strategy that requires minimal time and effort yet can still favorably alter knee biomechanics would be of substantial benefit to female athletes. To this end, evidence exists that increased heel height alters lower extremity biomechanics, including sagittal plane knee postures. Both static-standing and dynamic gait analyses have demonstrated increased knee flexion angles with increased heel height. It is unknown; however, if these findings will be evident during sports maneuvers, such as jump-landing or single limb hopping. If so, the incorporation of a heel lift may offer an alternative strategy for altering sagittal plane knee kinematics during sporting activities.

Therefore, the purpose of this study was to examine the effect of heel height on knee flexion angles at initial contact, peak flexion and the rate of excursion while performing a drop-landing and a forward hop. The authors hypothesized that increased heel height would significantly increase knee flexion at initial contact, increase peak knee flexion, and decrease the rate of excursion during both tasks.

METHODS

Subjects

Fifty female subjects between the ages of 18 and 25 (age = 20.6 ± 1.5 years, height = 166.2 ± 6.1 cm, weight = 64.3 ± 9.3 kg) were recruited from the university community via consecutive sampling procedures. Pilot data collection using identical procedures described below was performed on 10 female subjects to obtain subject size calculations for the current study. A readily available power analysis software program
and pilot testing. The application of the varying heel lifts was completed in random order. The subjects were not told which heel lift was being utilized in an effort to minimize bias.

Instrumentation
An electrogoniometer (EG) (Biometrics Ltd; Gwent, UK) that sampled at 2000 Hz was used to measure sagittal plane knee joint angles during the drop-landing testing procedure. Recent research has demonstrated intra-tester reliability coefficients for EG measurement of knee angles in static standing with various heel heights at 0.87-0.88. Bronner et al found that EG reliability correlation and accuracy were high (r≥0.999, SEM≤1.72°/H11034; respectively) and the concurrent validity correlations to a motion analysis criterion measure were also high (r≥0.991) when analyzing knee angle displacement during dance moves, including jumping. The manufacturer lists the EG’s accuracy at ±2° and repeatability at 1° over a 90° range.

A force plate (Bertec Corporation, Columbus, OH; sampled at 2000 Hz) securely mounted in the subfloor (such that the top surface of the force plate was level with the laboratory floor) was utilized to mark initial contact with the floor. Specifically, initial contact was determined to be when a minimal amount of force (10 N) applied to the force plate was detected by the acquisition software above a quiet baseline measured 100 ms prior to the event (Figure 1). The acquisition software was programmed to use the force plate as an event marker from which the data were recorded using a trigger sweep mode. The software system continually records and temporarily stores all data. This circular buffering allows the user to have access to data points up to one second prior to the event marker. A total of 1000 ms was recorded: 300 ms pre-contact and 700 ms post-contact for each trial. All hardware was connected to an analog-to-digital conversion board and a desktop computer (Dell; Austin, TX) thereby allowing synchronous collection of data from each of the respective sources. Raw data were acquired and filtered with a software acquisition and analysis system (Run Technologies; Laguna Hills, CA).

Procedures
Identical procedures were followed for each subject. Data collection was completed during one session.
Demographic data including height, weight, age, and the level and type of sport or activity was collected. All testing was performed on the dominant lower extremity. Dominance was determined by having the subject jump off a 20 cm wooden box and land on one leg. The lower extremity upon which the subject landed two out of three trials was considered the dominant lower extremity. The subjects were asked to demonstrate an ability to perform the landing task to be utilized in this study. Each task was described and the potential participant completed each activity. If an individual was unable to perform both landing tasks without restriction they were excused from participation in the study.

Subjects donned a standardized shoe (NewBalance, Model 600; Boston, MA) that was neutrally balanced (neither a supination or pronation bias) for the testing procedures. Subjects chose their own shoe size. Prior to donning the shoes, the investigator determined the order of the application of the heel lifts by randomly pulling papers labeled with the 3 different height measurements out of a hat. The subject was not told which heel height was being used for each trial. The heel lifts (G&W Heel Lift Incorporated; Cuba, MO) were injection-molded PVC vinyl lifts 12 mm in height. Two heel lifts were combined with double-sided tape provided by the manufacturer to achieve the 24 mm height (Figure 2). The investigator then affixed the appropriate heel lift to the undersurface of the subject's shoe with carpet tape (Ace Hardware Corp.; Oak Brook, IL).

Next, the EG was centered over the lateral joint line of the knee with the proximal block of the EG aligned with the greater trochanter and the distal block with the lateral malleolus. The end-blocks of the EG were attached to the subject's lateral leg with double sided adhesive tape and further secured with a thin foam wrap. Extra care was taken to ensure the foam wrap did not interfere with the optical fibers of the device. Once in place, the subject was asked to stand with her knee at 0° as verified by a manual goniometer, at which time the EG was zeroed.

**Drop-landing activity.** The subject stepped onto the 40 cm high platform and stood facing the force plate with her feet shoulder width apart and toes aligned with the edge of the platform. The platform was located 11 cm from the force plate. The subject then leaned and fell forward off the platform and landed in the middle of the force plate on her dominant lower extremity (Figure 3). The subject was instructed to maintain her balance on the single limb until cued by the investigator to place the other lower extremity on the floor. Failure to land in the middle of the force plate or to maintain single limb balance following the jump resulted in negation of that trial from the data set and the subject was asked to repeat the jump.

**Forward hop activity.** The subject stood with both lower extremities on the floor and feet shoulder width apart 45% of her height away from the force plate. A 12 cm tall box was placed halfway between the subject and the force plate. These procedures are similar to those found in previous studies.

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**Figure 1.** Example of force plate data output.

**Figure 2.** Heel lifts, placed on the external surface of standard shoe.
given a 30-second rest period between each jump to minimize the effect of fatigue. All data were gathered consecutively with a five-minute break between each condition to allow time to affix the heel lift and to give the subject a longer rest period.

**Data Reduction**

Kinematic, force plate and time data were signal averaged over all five trials of each task using the features available in the acquisition software. The acquisition software capabilities were used to report the values of the dependent measures. Sagittal plane knee joint excursion was calculated by subtracting the averaged knee angle at initial contact (KA_{IC}) from the peak knee flexion (KA_{Peak}) value. Rate of excursion (degrees/second) was calculated by dividing knee excursion by the time difference between maximum and initial contact knee flexion angles:

\[
\text{Rate of excursion} = \frac{\text{KA}_{\text{Peak}} - \text{KA}_{\text{IC}}}{\text{Time}_{\text{KA Peak}} - \text{Time}_{\text{KA IC}}}
\]

The knee angle measured at 250 ms was used as the peak knee flexion angle in the instance that peak knee flexion occurred later than 250 ms. Research investigating lower extremity kinematics in landing. The subject hopped forward from a static stance over the box and landed in the middle of the platform on the dominant lower extremity (Figure 4). The subject was instructed to maintain her balance on the single limb until cued by the investigator to place the other lower extremity on the floor. Failure to land in the middle of the force plate or to maintain single limb balance following the jump resulted in negation of that trial from the data set and the subject was asked to repeat the hop.

Each subject completed five trials of each landing task for all three heel lift conditions for a total of 30 jumps or trials. Most subjects were able to complete successful trials without the need to repeat additional jumps. In subjects who required an additional jump, on average only one negated trial occurred. The order of the landing activities was counterbalanced between each subject with the initial subject’s order being determined by flipping a coin. The subject was asked to repeat the hop.
The within subject variable was heel lift height with 3 levels: 0 mm, 12 mm, and 24 mm. The block factor was the individual subjects. When appropriate, post hoc testing using one-tailed paired t-tests with Bonferroni correction were performed to identify any significant differences in the dependent variables between the heel lift conditions. Alpha levels were set a-priori at \( p < 0.05 \). The corrected p-value used for each post hoc test was \( p < 0.017 \).

**RESULTS**

**Subjects:** Fifty females, 16 athletes and 32 recreationally active individuals, between the ages of 18 and 25 (age = 20.6 ± 1.5 years, height = 166.2 ± 6.1 cm, weight = 64.3 ± 9.3 kg) participated in this study. In order to better establish the homogeneity of our sample population Unpaired T-tests were utilized to compare the performance of the athletes and the recreationally active females at each heel lift level for the forward hop tasks. No significant differences were found between the two groups at the 0 mm heel lift level for knee angle at initial contact (\( p = 0.686 \)), peak knee flexion angle (\( p = 0.819 \)) or rate of excursion (\( p = 0.839 \)). No significant differences were found at the 12 mm heel lift level for knee angle at initial contact (\( p = 0.635 \)), peak knee flexion angle (\( p = 0.558 \)) or rate of excursion (\( p = 0.126 \)). No significant differences were found at the 24 mm heel lift level for knee angle at initial contact (\( p = 0.886 \)), peak knee flexion angle (\( p = 0.940 \)) or rate of excursion (\( p = 0.180 \)).

**STATISTICAL METHODS**

Statistical analysis was completed with a commercially available software package (SPSS; Chicago, IL). Separate repeated measures (randomized block) analysis of variances (ANOVA) were utilized to determine the influence of heel height on knee angle at initial contact, peak flexion and rate of excursion for each landing task. The within subject variable was heel lift height with 3 levels: 0 mm, 12 mm, and 24 mm. The block factor was the individual subjects. When appropriate, post hoc testing using one-tailed paired t-tests with Bonferroni correction were performed to identify any significant differences in the dependent variables between the heel lift conditions. Alpha levels were set a-priori at \( p < 0.05 \). The corrected p-value used for each post hoc test was \( p < 0.017 \).
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DISCUSSION

The purpose of this study was to determine if a heel lift had the ability to alter sagittal plane knee kinematics during landing. These data demonstrated an increase in initial contact and peak flexion angles exhibited by subjects when there was an addition of a 24 mm heel lift compared to the control condition during a forward hop task. Furthermore, the subjects’ rate of excursion decreased between the 12 and 24 mm lift conditions during this same task. For the drop-landing task, no significant changes in sagittal plane knee kinematics were observed between conditions. When subgroup comparison data were examined, no differences in the results were found between athletes and non-athletic active individuals in our study. Subjects’ sagittal plane knee kinematics responded similarly to

| Table 1. Comparison of the mean, standard deviation and standard error for all dependent measures at each heel lift height for the forward hop between athletes and recreationally active subjects. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | Athlete (n=16)  |                 | Recreationally Active (n=32) |                 |                 |                 |                 |
|                 | Mean | SD | SE  | Mean | SD | SE  | p-value |
| \( \text{KA}_{(IC)}(°) \) |     |     |     |     |     |     |     |
| 0mm             | 8.225 | 7.237 | 1.809 | 9.058 | 6.159 | 1.056 | 0.686 |
| 12mm            | 9.840 | 5.276 | 1.319 | 8.992 | 6.097 | 1.046 | 0.635 |
| 24mm            | 10.954 | 7.293 | 1.823 | 11.264 | 7.023 | 1.204 | 0.886 |
| \( \text{KA}_{(PEAK)}(°) \) |     |     |     |     |     |     |     |
| 0mm             | 47.526 | 10.061 | 2.515 | 46.761 | 11.349 | 1.946 | 0.819 |
| 12mm            | 49.389 | 10.061 | 2.515 | 47.528 | 10.557 | 1.810 | 0.558 |
| 24mm            | 48.970 | 9.808 | 2.452 | 48.744 | 9.813 | 1.683 | 0.940 |
| \( \text{RE}(°/sec) \) |     |     |     |     |     |     |     |
| 0mm             | 204 | 66 | 0.016 | 208 | 46 | 0.008 | 0.839 |
| 12mm            | 189 | 43 | 0.011 | 224 | 53 | 0.009 | 0.126 |
| 24mm            | 179 | 52 | 0.013 | 202 | 55 | 0.009 | 0.180 |

Abbreviations: \( \text{KA}_{(IC)} \), knee angle at initial contact; \( \text{KA}_{(PEAK)} \), peak knee angle; \( \text{RE} \), rate of excursion; SD, standard deviation; SE, standard error

all found to be significantly different (\( F_{2,98} = 9.705, p < 0.001, \text{eta}^2 = 0.165 \); \( F_{2,98} = 4.463, p = 0.014, \text{eta}^2 = 0.083 \); \( F_{2,98} = 4.108, p = 0.019, \text{eta}^2 = 0.077 \); respectively) when testing for heel lift differences. Post-hoc analyses revealed significant differences between the 0 and 24 mm lifts (\( p < .001 \)) and the 12 and 24 mm lifts (\( p = .003 \)), but not between the 0 and 12 mm conditions (\( p = .423 \)). A significant difference was noted between the 0 and 24 mm lift (\( p = .004 \)), but not between the 0 and 12 mm or the 12 and 24 mm conditions (\( p = .071 \) and \( p = .282 \), respectively). The mean values for rate of excursion decreased significantly from the 12 mm lift to the 24 mm lift (\( p = .004 \)). Rate of excursion did not differ from the 0 to 12 mm or the 0 to 24 mm lift conditions (\( p = .351 \) and \( p = .086 \), respectively).

**Drop-Landing Task:** Data collected during the jump-landing task revealed no significant differences for knee angle at initial contact (\( F_{2,98} = 0.657, p = 0.521, \text{eta}^2 = 0.013 \)), peak flexion (\( F_{2,98} = 0.300, p = 0.741, \text{eta}^2 = 0.006 \)), or rate of excursion (\( F_{2,98} = 1.689, p = 0.190, \text{eta}^2 = 0.033 \)) across the heel lift conditions (Table 2).
added heel height despite any differing level of activity or training.

**Forward Hop**

*Initial Contact and Peak Knee Flexion Measures.* When performing the forward hop task onto a single, dominant limb with participants wearing a neutral, non-wedged athletic shoe the addition of a 12 mm heel lift did not significantly alter initial contact angle. However, a 24 mm heel lift did increase subjects’ knee flexion angle at landing. Similar results were seen with peak knee flexion following landing from a forward hop.

The results of this study paralleled research that has previously evaluated the influence of elevated heel height on sagittal plane knee posture in both static and dynamic gait situations. DeLateur et al demonstrated that an increase in heel height was related to an increase in knee flexion angle in static stance. Ebbling et al demonstrated that knee flexion angles at initial contact and peak knee flexion angle increased along with the increased heel height during the stance phase of ambulation. The data presented in this manuscript also demonstrated that a greater knee flexion angle occurred with increased heel height. The 12 mm lift failed to demonstrate a notable increase in this measure, while the 24 mm lift generated a greater increase in the knee flexion angle.

The discrepancy between the 12 mm and 24 mm lift may suggest that a minimum threshold exists for the effect of heel height on knee angle. At initial contact, the change in knee angle between 12 mm and 24 mm conditions was statistically different. Perhaps a minimum of 24 mm lift height in necessary to impart a change in knee flexion during a forward hop maneuver. Another consideration is that the minimum threshold

---

**Table 2.** Mean, standard deviation and standard error for all dependent measures at each heel lift height for the forward hop and drop-landing tasks. (n = 50)

<table>
<thead>
<tr>
<th></th>
<th>Forward Hop</th>
<th>Drop-Landing</th>
<th>p-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0mm</td>
<td>12mm</td>
<td>24mm</td>
<td>p-value</td>
</tr>
<tr>
<td>$K_{A_{IC}}(°)$</td>
<td></td>
<td></td>
<td></td>
<td>*&lt;0.001</td>
</tr>
<tr>
<td>Mean</td>
<td>8.801</td>
<td>9.263</td>
<td>11.165</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>6.459</td>
<td>5.806</td>
<td>7.037</td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>0.913</td>
<td>0.821</td>
<td>0.995</td>
<td></td>
</tr>
<tr>
<td>$K_{A_{PEAK}}(°)$</td>
<td></td>
<td></td>
<td></td>
<td>*0.014</td>
</tr>
<tr>
<td>Mean</td>
<td>47.005</td>
<td>48.123</td>
<td>48.816</td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>1.535</td>
<td>1.462</td>
<td>1.373</td>
<td></td>
</tr>
<tr>
<td>RE(°/sec)</td>
<td></td>
<td></td>
<td></td>
<td>†0.019</td>
</tr>
<tr>
<td>Mean</td>
<td>207</td>
<td>212</td>
<td>195</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>52</td>
<td>52</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>0.007</td>
<td>0.007</td>
<td>0.008</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: $K_{A_{IC}}$, knee angle at initial contact; $K_{A_{PEAK}}$, peak knee angle; RE, rate of excursion; SD, standard deviation; SE, standard error

* significantly different from 0mm condition
†significantly different from 12mm condition
lies somewhere between 12 mm and 24 mm. Ebbling et al. did not compare their data to a neutral (0 mm) heel height condition, and no other studies were found that looked at comparable heel heights and knee kinematics to those used in this study. However, Bird et al. and Traino et al. demonstrated that a minimum heel height of 20 mm was necessary to generate any significant changes in EMG activity during static stance and gait activities.

Rate of Excursion. The data is this study demonstrated that an overall lengthening of the time required to achieve peak knee flexion occurred despite the total excursion from initial contact remaining the same. In other words, our participants achieved the same amount of knee flexion range-of-motion over a longer period of time. For example, peak knee flexion was achieved 191.05 ms after initial contact at baseline and 200.99 ms after initial contact when wearing the 24 mm heel lift. No research has been identified that investigated the influence elevated heel height has on excursion or rate of excursion at the knee. It is possible that the slower rate of excursion is related to muscle activity, a variable that we did not explore in this study. Edwards et al. found that EMG activity in the vastus medialis and vastus lateralis muscles increased with increasing heel height during sit to stand tasks. Kerrigan et al. demonstrated prolonged knee flexor torque during the stance phase of walking when subjects donned high-heeled shoes. It is possible that an increased level of quadriceps activity could slow the eccentric knee flexion that occurs with landing from a jump thus slowing the rate of flexion. Further research is necessary to investigate this relationship.

The rate of knee excursion may also have been influenced by the kinematic alterations at other joints. Johanson et al. found that higher heel heights increased ankle dorsiflexion excursion and delayed time to heel off during walking tasks. Ankle joint kinematics were not addressed in this current study. However, the authors speculated that at heel contact the ankle was positioned in more plantarflexion to achieve the increased excursion. If this was true in our study, then it may be possible that the tibia required more time to progress forward over the ankle complex and would alter the mechanical timing at the knee as well. Additional research is required to elucidate this idea.

Drop Landing

Initial Contact and Peak Knee Flexion Measures. Our data failed to demonstrate any effect of heel height on knee angle at initial contact or peak knee flexion angle while performing a drop-landing task onto a single limb. No past research was identified that explored the influence heel height has on knee posture when landing from a jump, thus it is difficult to explain why the data from the drop-landing maneuver varied so differently from our data from the forward hop. One potential factor is the variance in the specific landing techniques between the two maneuvers. The researchers observed that participants landing from the jump-landing task landed with a more accentuated forefoot landing style compared to landing from the forward hop. While this was only a visual observation, it has been demonstrated in other research that subjects landing from a more vertically oriented jump demonstrate a larger degree of ankle plantarflexion and utilize a forefoot landing strategy. DiStefano et al. measured ankle kinematics at initial contact after landing from a jump-landing maneuver and found the average plantarflexion angle to be 37.8°. However, studies utilizing a forward hop maneuver describe that the participants rely more on a heel contact style of landing. While we did not measure ankle kinematics during our study, it is possible that the foot and ankle position of our participants at initial contact when performing the drop-landing task was such that the heel lift would not be in contact with the ground and thus be unable to alter knee kinematics during landing.

Additionally, the rate at which knee flexion occurred may have coincided with the eccentric dorsiflexion movement at the ankle and the participants could have reached peak knee flexion prior to full rearfoot contact, thus not utilizing the heel lift during the knee excursion portion of the maneuver. While DiStefano et al. did not document measures associated with heel contact, they did demonstrate that the knee achieved peak knee flexion prior to the ankle achieving peak dorsiflexion, suggesting that the rate of excursion of the ankle is slower than that of the knee despite a smaller magnitude of excursion. It seems possible that the joint kinematics at the ankle when landing from a jump-landing maneuver minimize the potential influence of a heel lift on the knee.
Rate of Excursion. As with the knee angle measurements at initial contact and peak flexion, the rate of excursion results were not significantly changed as a result of the heel lift variables. However, if the heel lift failed to influence the knee position at different points in time throughout the landing maneuver, then it stands to reason that the lift would also have no impact on the rate at which the joint displacement occurred.

Clinical Significance/Relevance
Three dependent measures were examined and were found to be statistically significantly different between conditions. These dependent measures were knee angle at initial contact, maximum knee flexion angle, and rate of excursion during the forward hop task. However, even given the statistically significant differences, one has to question whether these results would be considered clinically important. In order to evaluate clinical importance the effect size related to the interventions can be studied. The representation of effect size utilized by SPSS for an ANOVA is the Eta Squared (Eta²). The value falls in a range from zero (0) to one (1), where a number closer to one represents a more potent independent variable. Portney and Watkins described the value 0.5 as representing a “medium” effect size, and constitutes an intervention that causes change that is visible to the eye. The effect sizes from our data points found to be statistically significant ranged from 0.077 (rate of excursion) to 0.165 (knee angle at initial contact), representing a small effect size at best. Looking directly at the difference in the means across lift conditions, it is evident that the magnitudes of the changes were quite small. For example, the increase in knee flexion angle at initial contact between the 0 mm and 24 mm lift conditions increased by only 2.36°. Though statistically significant, it is unknown whether this change would have a clinically relevant impact. On the surface it appears unlikely that one would predict any significant clinical differences at this level. However, the heel lift intervention strategy is a novel idea and additional research is needed to make any clear determinations.

Landing with the knee in angles closer to extension and achieving peak knee displacement over a shortened period of time have been established as a risk factor for ACL injury. Theoretically, increasing knee flexion (both at initial contact and a peak displacement) and slowing the rate of excursion should reduce the impact of these risk factors. This has been the goal of a number of exercise-based intervention programs. A few have been successful in positively altering such kinematics following extensive training. The training, however, typically requires a large time and financial commitment. We wanted to examine if an alternative intervention strategy, one requiring less aggressive changes to an individual’s typical daily regimen, would have similar results in altering knee kinematics. The current study did not directly examine sagittal plane knee kinematics as related to the strain on the ACL or the risk for injury. However, similar to the exercise-intervention studies, we were able to demonstrate that the addition of a heel lift to athletic shoe wear increased knee flexion at initial contact and at peak displacement while also slowing the rate of excursion following a forward hop maneuver. We are not able to comment on whether the magnitude of this change was enough to alter the level of risk associated with ACL strain in our subjects. Additional research is necessary to elucidate the clinical impact our lift intervention truly has on the female athletic population.

Limitations
Limited data sources: The current study only investigated the influence a heel lift has on sagittal plane knee kinematics during landing tasks in females. This limited the conclusions that could be drawn from the current data to that of knee flexion-extension range-of-motion characteristics. The authors are not able to comment on any potential influence a heel lift might impart on coronal or transverse plane kinematics at the knee. Also, the current study did not examine how alterations in ankle joint kinematics and kinematics may have affected the knee mechanism. Furthermore, EMG data on the musculature around the knee was not collected during the two functional tasks, and thus the authors do not know how this may have been affected by the addition of a heel lift during the landing maneuvers. Researchers have demonstrated that a strong association exists between extended knee posture at initial contact, limited knee excursion, and faster rates of excursion at the knee and the potential risk factors
for ACL injury in female athletes. Thus, the authors of the current study felt that collecting sagittal plane goniometric measures at the knee was well justified, however, we acknowledge that other data sources should also be explored.

External Validity: The current study was conducted in a controlled environment within a laboratory. The landing activities that were utilized were performed without distraction, beginning in a static position. Therefore, it is impossible to speculate on how a heel lift would influence sagittal plane knee kinematics during a similar task performed during a real-time sporting event. However, as is the nature of clinical research, the authors felt that it was appropriate to conduct a controlled laboratory trial before a field study. Further controlled research is needed to determine if heel lifts are effective enough to warrant research in more “real-life” scenarios.

Another limitation of the current study was that the authors are unable to predict any potential negative effects from utilizing an altered heel lift height in athletic shoe wear. As this intervention has not been investigated for landing tasks previous to the current study, no data exists to suggest whether an elevated heel could have a negative impact on performance, joint integrity, or the overall safety of the individual. Again, future research and longitudinal studies would be necessary to discover if any problems would arise from the use of heel lifts.

Future research
The heel lift intervention investigated in this study is new and unique to ACL injury prevention research. The information gathered offers new insight into the potential for alternative methods to address ACL injury risk factors in female athletes in addition to those previously explored. Additional research questions based on the findings of this study include whether there is a minimum heel lift height needed to impart any biomechanical changes at the knee and what sports maneuvers could be influenced by a lift that size. If future studies do reveal that heel lifts have a substantial role in altering lower extremity biomechanics, and could minimize potential risk factors for injury, it would behoove researchers to then look more directly at the potential influence directly on the ACL.

Conclusions
The addition of a 24 mm heel lift alters sagittal plane knee kinematics, specifically knee angle at initial contact, peak knee flexion angle, and rate of excursion, when performing a forward hop task. However, a 12 mm heel lift failed to impart any significant changes in these measures during the same task. When performing a drop-landing task, the addition of either a 12 mm or 24 mm heel lift did not alter sagittal plane knee kinematics. Further research is needed to understand the potential that various heel lift heights may have on knee biomechanics in all planes of motion, on joints other than the knee, and during sport-related maneuvers other than those explored in this study.

REFERENCES


ABSTRACT

Background: Lower limb injuries are a large problem in athletes. However, there is a paucity of knowledge on the relationship between alignment of the medial longitudinal arch (MLA) of the foot and development of such injuries. A reliable and valid test to quantify foot type is needed to be able to investigate the relationship between arch type and injury likelihood. Feiss Line is a valid clinical measure of the MLA. However, no study has investigated the reliability of the test.

Objectives: The purpose was to describe a modified version of the Feiss Line test and to determine the intra- and inter-tester reliability of this new foot alignment test. To emphasize the purpose of the modified test, the authors have named it The Navicular Position Test.

Methods: Intra- and inter-tester reliability were evaluated of The Navicular Position Test with the use of ICC (interclass correlation coefficient) and Bland-Altman limits of agreement on 43 healthy, young, subjects.

Results: Inter-tester mean difference -0.35 degrees [-1.32; 0.62] p = 0.47. Bland-Altman limits of agreement -6.55 to 5.85 degrees, ICC = 0.94. Intra-tester mean difference 0.47 degrees [-0.57; 1.50] p = 0.37. Bland-Altman limits of agreement -6.15 to 7.08 degrees, ICC = 0.91.

Discussion: The present data support The Navicular Position Test as a reliable test of the navicular bone position during rest and loading measured in a simple test set-up.

Conclusion: The Navicular Position Test was shown to have a high intraday-, intra- and inter-tester reliability. When cut off values to categorize the MLA into planus, rectus, or cavus feet, has been determined and presented, the test could be used in prospective observational studies investigating the role of the arch type on the development of various lower limb injuries.

Key Words: Foot, Feiss Line, reliability, alignment, pronation
INTRODUCTION
Overuse injuries in the lower extremity are numerous, costly, and represent a large clinical problem.\textsuperscript{1,2} Despite the extent of the problem, there is a paucity of knowledge on the cause of the injuries.\textsuperscript{3-6} Meeuwisse et al.\textsuperscript{7} published a dynamic model of etiology in sport injury where exposure to an injury is the result of a combination of possessing a risk factor and then participating in events with lesser or greater degrees of risk involved. The function and structure of the medial longitudinal arch (MLA) of the foot has been proposed as a risk factor for developing injuries.\textsuperscript{8-10} Increased navicular drop (ND) has been determined to be a risk factor for sustaining injuries among female novice runners when preparing for a four mile running event.\textsuperscript{10} Along the same line, different arch structures have been found to be associated with specific injury patterns with high arched runners reporting a greater incidence of ankle injuries, stress fractures of the fifth metatarsal and iliotibial band friction syndrome.\textsuperscript{11}

In general low arched runners exhibited more knee pain, patellar tendinitis and plantar fasciitis.\textsuperscript{8} This is supported by several studies demonstrating an increased ND to be associated with a greater risk of developing exercise related lower leg pain and patellofemoral pain syndrome.\textsuperscript{9,12} However, no clear link between foot posture and injury likelihood exists\textsuperscript{13-15} and instead other risk factors are suggested as potential deleterious and main cause of the injuries. One reason for discrepancy may be the result of the lack of reliable and valid field methods of determining the MLA and biomechanical characteristics of the foot during loading.

Visual assessment of MLA has been proposed\textsuperscript{16} but found not to be reliable and valid.\textsuperscript{17,18} As a consequence, different static tests have been developed to attempt to quantify the position of MLA\textsuperscript{19-22} including the Navicular Drop Test and the Arch Index. These methods have been proven to be valid and reliable\textsuperscript{23-26} but despite their validity they do not take into account the effect of foot sizes on the relative drop of the navicular bone\textsuperscript{27} which may lead to misinterpretations when used in a mixed population as in a normal clinical setting. The Feiss Line test\textsuperscript{2,28} has been suggested to be a valuable tool as it relates to the position of the navicular during rest and loading in relation to the line between the medial malleolus and the first metatarsal head rather than to the height of the ND during loading. In addition the Feiss Line test is easy to conduct and requires no additional measuring devices apart from a pen and goniometer. Furthermore, the test does not require identification of the subtalar neutral position. This is recommended since the exact localisation of neutral position is extremely difficult and not reliable.\textsuperscript{29}

Recently, McPoil\textsuperscript{30} described the difficulty in the identification of the neutral position as a possible factor contributing to the moderate levels of inter-rater reliability provided by the ND test. However using the Feiss Line test it is possible to quantify the MLA using a simple setup, without the need for identification of subtalar neutral position. The Feiss Line is defined as an imaginary straight line from the medial malleolus through the navicular bone to the center of the head of the first metatarsal.\textsuperscript{2} For the purposes of this study the original Feiss Line test had to be modified to increase the accuracy and usefulness of the test in clinical practice. This requires that the navicular in a neutral foot is positioned upon the modified Feiss Line. By changing the position of one end of the Feiss Line from the original position on the medial malleolus to a parallel shifted point on the Achilles tendon and retaining the original point from the Feiss Line on the first metatarsal head, a resultant lowering of the Feiss Line occurs. Thus, the navicular is placed on the line in the neutral foot. This makes the definition of pes rectus, pes planus and pes cavus easier for clinicians, as the navicular is placed below and above the new Feiss line in low or high arched individuals, respectively. Before the new line can be recommended to clinicians and applied in research and clinical work it has to be tested for reliability and validity.

The aim of the present study was to describe the modified Feiss Line and to determine the intra- and inter-tester reliability of this new Navicular Position Test (NPT). In the current study no attempt was made to establish validity of the NPT.

METHODS
All participants in this study were volunteers at a large badminton tournament in Denmark [n = 43; 17 women and 26 men; age 23 y (18 to 40 y)]. The study
The position of the navicular bone was measured with the center of the goniometer on the navicular tuberosity and the arms of the goniometer on the head of the first metatarsal and the marking on the Achilles tendon, respectively (Figure 3). The angle between two visualized straight lines; 1) between the head of the first metatarsal bone and navicular tuberosity and 2) between the marking on the Achilles tendon and the navicular tuberosity (Figure 4). The increment of measurement of the goniometer used in this study was 2.5 degrees.

STATISTICAL METHODS

Interclass correlations coefficients (ICC (3,k)) were calculated in order to compare the relationship between measures. Bland and Altman’s 95% limits of agreement was approved by the Ethical Committee KF:01-045/03. The participants were tested by inexperienced physiotherapy students three times, twice by the one clinician and once by the other to determine the within day intra- and inter-tester reliability. The examination was conducted in two separate rooms, allowing no communication and ensuring that all data was blinded for the assessors. Following the measurements the markings on the foot were removed completely with alcohol by a third researcher allowing the clinicians to be fully blinded. Randomizing the order of the participants when retesting further ensured blinding in the intra-tester assessment.

The test measurements were conducted on the right foot only. The participant stood in an upright position, toes pointing straight forward, with the right foot behind the left with the left heel and right toe on the same transverse plane. The right knee was placed vertically above the first and second toe (Figure 1). The subjects were allowed to hold a metal stick for support. The clinician marked the medial side of head of the first metatarsal bone, then the navicular tuberosity, and finally a point at the Achilles tendon (Figure 2). Marking the Achilles was done by marking the apex of the medial malleolus, then measuring the height from the floor and projecting posteriorly to a point horizontal to the dorsal edge of the Achilles tendon.
cavus foot displays a positive number, while a neutral foot would display a straight line.

RELIABILITY

ICC value for intra-rater reliability was 0.94 with a range of 0.88 – 0.97, while inter-rater reliability was 0.91 with a range on 0.83 – 0.95. Spearman’s rho mean value of the degree of agreement between the two clinicians, R², Bias, and Standard Deviation (SD) of the Bias was calculated (Table 2). The intra- and inter-rater agreement was calculated using Bland-Altman plot with 95% limits of agreement (Table 3). For the intra-rater reliability the mean and standard deviation of the difference between measurements was estimated to 0.47 (–0.57; 1.50) degrees and SD = 3.37 degrees.

DESCRIPTIVE RESULTS

The distribution of the NPT measures on the 43 participants was relatively symmetric (Figure 5). The feet measured ranged from –12.5 to 15 degrees and the mean value for the total number of measures was 0.91 degrees (95% CI = –0.03 to 1.85) (Table 1). The pes planus foot displays a negative number and a pes cavus foot displays a positive number, while a neutral foot would display a straight line.

Table 1. Descriptive Data for all subjects (n = 43), for Raters 1 and 2.

<table>
<thead>
<tr>
<th></th>
<th>Clinician 1 Test 1</th>
<th>Clinician 1 Test 2</th>
<th>Clinician 2 Test 1</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number (n)</td>
<td>43</td>
<td>43</td>
<td>43</td>
<td>129</td>
</tr>
<tr>
<td>Mean degrees (Range)</td>
<td>0.87 (–0.73 to 2.47)</td>
<td>0.76 (–0.76 to 2.26)</td>
<td>1.10 (–0.81 to 3.01)</td>
<td>0.91 (–0.96 to 1.88)</td>
</tr>
<tr>
<td>Variance</td>
<td>27.05</td>
<td>24.27</td>
<td>38.48</td>
<td>29.49</td>
</tr>
<tr>
<td>Standard deviation (SD)</td>
<td>5.20</td>
<td>4.93</td>
<td>6.20</td>
<td>5.43</td>
</tr>
<tr>
<td>Standard error (SE)</td>
<td>0.79</td>
<td>0.75</td>
<td>0.95</td>
<td>0.48</td>
</tr>
<tr>
<td>SE corrected</td>
<td>1.6</td>
<td>1.52</td>
<td>1.91</td>
<td>0.97</td>
</tr>
<tr>
<td>Skewness (SE)</td>
<td>0.12 (±0.36)</td>
<td>0.16 (±0.36)</td>
<td>0.24 (±0.36)</td>
<td>0.21 (±0.21)</td>
</tr>
<tr>
<td>Kurtosis (SE)</td>
<td>-0.72 (±0.71)</td>
<td>-0.11 (±0.71)</td>
<td>-0.48 (±0.71)</td>
<td>-0.40 (±0.42)</td>
</tr>
</tbody>
</table>

Table 2. Correlation of Intra- and Inter-rater reliability.

<table>
<thead>
<tr>
<th>Intra-observer reliability</th>
<th>Clinician 1 Test 1 vs. Clinician 1 Test 2</th>
<th>Spearman’s rho Mean</th>
<th>P-value (two-tailed)</th>
<th>Agreement</th>
<th>R²</th>
<th>ICC (Range)</th>
<th>Bias</th>
<th>SD of the Bias</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.88</td>
<td>P&lt;0.01</td>
<td>37 %</td>
<td>0.79</td>
<td>0.94 (0.88 – 0.97)</td>
<td>0.12</td>
<td>2.50</td>
</tr>
<tr>
<td>Inter-observer reliability</td>
<td>Clinician 1 Test 1 vs. Clinician 2 Test 1</td>
<td>0.87</td>
<td>P&lt;0.01</td>
<td>33 %</td>
<td>0.77</td>
<td>0.91 (0.83 – 0.95)</td>
<td>-0.23</td>
<td>3.31</td>
</tr>
<tr>
<td></td>
<td>Clinician 1 Test 2 vs. Clinician 2 Test 1</td>
<td>0.91</td>
<td>P&lt;0.01</td>
<td>33 %</td>
<td>0.82</td>
<td>0.91 (0.84 – 0.95)</td>
<td>-0.35</td>
<td>3.16</td>
</tr>
</tbody>
</table>

Table 3. Bland-Altman plot with 95% limits of agreement in degrees. Positive numbers represent a pes cavus foot and negative numbers a pes planus foot.

<table>
<thead>
<tr>
<th>Agreement within the same clinician</th>
<th>95 % Limit of agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agreement between clinicians</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Agreement within the same clinician</td>
</tr>
<tr>
<td>Agreement between clinicians</td>
<td>Agreement between clinicians</td>
</tr>
</tbody>
</table>
NPT during walking and running may exist. However, this has to be investigated in future studies.

It must be emphasized, that soft tissue variation due to the amount of fat mass may mislead the clinician to evaluate the foot as pes planus even though the bony structures are in a neutral position if the MLA is evaluated visually without quantitative measures. Visual assessment of the arch height has been found to be unreliable, illustrating the need for objective standards and quantitative methods. Using easily identifiable bony landmarks was an attempt by the authors of this paper to increase reproducibility by providing testing standards. Moreover assessment that utilizes the navicular bone may provide a better indication of typical foot function during walking as compared to classic rear-foot assessments.

One limitation of the present study is the studies rather small sample size (n=43) that consisted of active badminton players that may, despite the relatively normal distribution, not be representative of the majority of people. Subjects were both symptomatic and asymptomatic in regard to lower extremity which makes the sample likely to represent a broad spectrum of foot types. The mean foot measurement in this study was 0.91 degrees or slightly pes cavus, as the pes cavus foot displays a positive number and a pes planus foot displays a negative number. The authors of this study made no attempt to establish numerical classification of foot types using this measurement. In order to establish limits or guidelines for meaningful classification of foot types and to assess whether the presented values agreement are of sufficient accuracy further studies need to be performed. Such studies examining the difference between pathologic and non pathologic feet, with a broader range of subjects are needed. When cut off limits are determined, prospective studies on healthy subjects could be conducted to investigate if time to injury differs among persons with different arch heights or foot types. Such studies may provide new insight about the possible role of certain foot types as a risk factor leading to injury in the lower extremity.

CONCLUSION

The NPT described and examined in this study has an within day intra-tester- and inter-tester reliability, measured by the Intraclass Coefficients of 0.94.
and −0.91, respectively. In 95% of the measurements the same clinician can measure within −6.15 to 7.08 degrees while different clinician’s measure within −6.55 to 5.85 degrees. The mean value of the NPT measurements performed was 0.91 degrees. This suggests that the NPT would be very easy to use in the clinic as the average or neutral foot will have the three NPT marks aligned very close to a straight line. The NPT is a simple test that can be used to clinically evaluate the position of the navicular bone in a weight bearing position. Future studies must be conducted to establish cut off limits to categorize the foot into planus, rectus, and cavus foot types. Then, prospective studies can be conducted to investigate if athletes with planus and cavus feet are at higher risk for sustaining injuries when compared athletes with a rectus foot.

REFERENCES

23. Jonson SR, Gross MT. Intraexaminer reliability, interexaminer reliability, and mean values for nine lower extremity skeletal measures in healthy naval


ABSTRACT

Purpose/Background: Previous research studies by Bolga, Ayotte, and Distefano have examined the level of muscle recruitment of the gluteal muscles for various clinical exercises; however, there has been no cross comparison among the top exercises from each study. The purpose of this study is to compare top exercises from these studies as well as several other commonly performed clinical exercises to determine which exercises recruit the gluteal muscles, specifically the gluteus medius and maximus, most effectively.

Methods: Twenty-six healthy subjects participated in this study. Surface EMG electrodes were placed on gluteus medius and maximus to measure muscle activity during 18 exercises. Maximal voluntary muscle contraction (MVIC) was established for each muscle group in order to express each exercise as a percentage of MVIC and allow standardized comparison across subjects. EMG data were analyzed using a root-mean-square algorithm and smoothed with a 50 millisecond time reference. Rank ordering of the exercises was performed utilizing the average percent MVIC peak activity for each exercise.

Results: Twenty-four subjects satisfied all eligibility criteria and consented to participate in the research study. Five of the exercises produced greater than 70%MVIC of the gluteus medius muscle. In rank order from highest EMG value to lowest, these exercises were: side plank abduction with dominant leg on bottom (103%MVIC), side plank abduction with dominant leg on top (89%MVIC), single limb squat (82%MVIC), clamshell (hip clam) progression 4 (77%MVIC), and front plank with hip extension (75%MVIC). Five of the exercises recruited gluteus maximus with values greater than 70%MVIC. In rank order from highest EMG value to lowest, these exercises were: front plank with hip extension (106%MVIC), gluteal squeeze (81%MVIC), side plank abduction with dominant leg on top (73%MVIC), side plank abduction with dominant leg on bottom (71%MVIC), and single limb squat (71%MVIC). Four of the exercises produced greater than 70%MVIC for both gluteus maximus and medius muscles.

Conclusions: Higher %MVIC values achieved during performance of exercises correlate to muscle hypertrophy. By knowing the %MVIC of the gluteal musculature that occurs during various exercises, potential for strengthening of the gluteal muscles can be inferred. Additionally, exercises may be rank ordered to appropriately challenge the gluteal musculature during rehabilitation.

Keywords: gluteus medius, gluteus maximus, muscle recruitment, rehabilitation exercise

1 Belmont University, Nashville, TN, USA
This study was approved by the Institutional Review Board at Belmont University and informed consent was obtained from all subjects. This project was completed for partial fulfillment of a degree.

The authors would like to thank Dr. John Halle and Dr. Patrick Sells for their advice and assistance with statistical analysis, as well as Mr. Anthony Carey for the donation of Core-Tex™ equipment.

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INTRODUCTION
The lower extremity functions in a kinematic chain, leading many researchers in recent years to examine the mechanical effect of weak proximal musculature on more distal segments.\(^1\,\^2\) Previous research by Distefano,\(^3\) Bolgla,\(^4\) and Ayotte\(^5\) has sought to determine the most appropriate exercises to strengthen the gluteal muscles due to their role in maintaining a level pelvis and preventing hip adduction and internal rotation during single limb support.\(^1\,\^6\) Measurement of such femoral torsion and pelvic rotation in the transverse plane, along with measurement of pelvic tilt in the sagittal plane can indicate abnormal alignment of the hip joint.\(^7\) Numerous pathologies have been described which are related to the inability to maintain proper alignment of the pelvis and the femur, including: tibial stress fracture,\(^8\) low back pain,\(^9,\^10\) iliotibial band friction syndrome,\(^1\,\^11\) anterior cruciate ligament injury,\(^1,\^12\) and patellofemoral pathology.\(^2,\^13,\^14,\^15,\^16,\^17\) While Distefano,\(^3\) Bolgla,\(^4\) and Ayotte\(^5\) have examined a wide range of exercises used to strengthen the hip musculature, to the knowledge of the authors, no cross comparison amongst the top exercises from each study has been performed.

Similar to Distefano,\(^3\) Ayotte,\(^4\) and Bolgla,\(^5\) exercises examined in the current study were rank ordered according to their recruitment of specific gluteal musculature and expressed as a percent of the subject's maximum volitional isometric contraction (MVIC). By knowing the approximate percentage of MVIC (%MVIC) recruitment of each of the gluteal muscles in a wide variety of exercises, the exercises may be ranked to appropriately challenge the gluteal musculature. MVIC was established in the standard manual muscle testing positions for gluteus medius and maximus, as described by Daniels and Worthingham.\(^18\) The use of the sidelying abduction position is supported by the results of Widler,\(^19\) where similarity in EMG activity for weight bearing and sidelying abduction (ICC's 0.880 and 0.902 for the respective positions) demonstrated that it is acceptable to use the MVIC value obtained during the standard manual muscle test position in order to establish a percentage MVIC for a weight bearing exercise.

Several previously published research articles helped to establish the parameters for determining a sufficient level of muscle activation for strength gains referenced in the current study. Anderson found that in order for strengthening adaptation to occur, muscle stimuli of at least 40-60% of a subject's MVIC must occur.\(^20\) When quantifying muscular strength, work by Visser correlates the use of a MVIC and a one-repetition maximum.\(^21\) In order to gain maximal muscular hypertrophy, Fry's work suggests an 80-95% of a subject's one repetition maximum must be achieved.\(^22\) Based on the work by Anderson,\(^20\) Visser,\(^21\) and Fry,\(^22\) for the purposes of this study, exercises producing greater than 70%MVIC were deemed acceptable for enhancement of strength.

Distefano examined electromyography (EMG) signal amplitude normalized values of gluteus medius and gluteus maximus muscles during exercises of varying difficulty in order to determine which exercises most effectively recruit these muscles.\(^3\) Rank order of exercises and %MVIC of Distefano's study can be viewed in Table 1. Of the top five exercises for the gluteus medius described by Distefano, the authors of the current study chose to reexamine sidelying hip abduction, single limb squat, and the single limb deadlift. Lateral band walk was not included in the current study as the researchers wished to only examine exercises that required no external resistance.

Research by Bolgla and Uhl also examined the magnitude of hip abductor muscle activation during rehabilitative exercises.\(^4\) Their results may be viewed in Table 2. Of the exercises studied by Bolgla et al, the authors of the current study chose only to look at the pelvic drop and sidelying hip abduction. These two exercises were chosen since the primary intention of the current study was to compare an exercise's recruitment of the gluteal musculature, and not the activation effects of weight bearing versus non-weight bearing on the musculature.

Finally, Ayotte et al. used EMG to analyze lower extremity muscle activation of the pelvic stabilizers as well as the quadriceps complex during five unilateral weight bearing exercises,\(^5\) displayed in Table 3. The authors of the current study elected to forgo analyzing a single-limb wall squat and a single-limb mini-squat due to their similarity to the single-limb squat. Forward step-up and lateral step-up were included in the current analysis. The current study serves to compare top exercises from these previously published studies, as well as several other commonly performed
informed consent form as well as a health history form and comprehensive lower quarter screen to identify exclusionary criteria. Pain when performing exercises, current symptoms of injury, history of ACL injury or any lower extremity surgery within past two years, and age of less than 21 years were criteria for exclusion.

Testing Procedures
EMG data were collected and analyzed on the dominant leg, identified by which leg the subject used to kick a ball.3,5,23 Alcohol wipes were used to clean the skin over the gluteal region prior to electrode placement. Schiller Blue Surface electrodes (Schiller America Inc.; Doral, FL) were placed over the gluteus medius and gluteus maximus muscles of the subject’s dominant leg, and EMG data were collected and analyzed.

### METHODS

**Subjects**
This study was approved by the Institutional Review Board of Belmont University. A total of 26 subjects were recruited from within the university and surrounding community through flyers and word of mouth. Healthy subjects who were able to perform exercise for approximately one hour were included in the study and reported to the laboratory for a single testing session. At this time they completed an informed consent form as well as a health history form and comprehensive lower quarter screen to identify exclusionary criteria. Pain when performing exercises, current symptoms of injury, history of ACL injury or any lower extremity surgery within past two years, and age of less than 21 years were criteria for exclusion.

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### Clinical Exercises
Clinical exercises were used in order to determine the exercises that are most effective at recruiting the gluteus maximus and medius.

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### Table 1. Findings of Distefano et al.3 Values are described as %MVIC, followed by rank in parentheses

<table>
<thead>
<tr>
<th>Exercise Condition</th>
<th>Glut Max %MVIC (rank)</th>
<th>Glut Med %MVIC (rank)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side-lying hip abd</td>
<td>39 (6)</td>
<td>81 (1)</td>
</tr>
<tr>
<td>Clam with 30 hip flex</td>
<td>34 (10)</td>
<td>40 (10)</td>
</tr>
<tr>
<td>Clam with 60 hip flex</td>
<td>39 (6)</td>
<td>38 (12)</td>
</tr>
<tr>
<td>Single-limb squat</td>
<td>59 (1)</td>
<td>64 (2)</td>
</tr>
<tr>
<td>Single-limb deadlift</td>
<td>59 (1)</td>
<td>58 (4)</td>
</tr>
<tr>
<td>Lateral band walk</td>
<td>27 (12)</td>
<td>61 (3)</td>
</tr>
<tr>
<td>Forward lunge</td>
<td>44 (4)</td>
<td>42 (9)</td>
</tr>
<tr>
<td>Sideways lunge</td>
<td>41 (5)</td>
<td>39 (11)</td>
</tr>
<tr>
<td>Transverse lunge</td>
<td>49 (3)</td>
<td>48 (6)</td>
</tr>
<tr>
<td>Forward hop</td>
<td>35 (8)</td>
<td>45 (8)</td>
</tr>
<tr>
<td>Sideways hop</td>
<td>30 (11)</td>
<td>57 (5)</td>
</tr>
<tr>
<td>Transverse hop</td>
<td>35 (8)</td>
<td>48 (6)</td>
</tr>
</tbody>
</table>

### Table 2. Findings by Bolgla and Uhl,4 represented as %MVIC.

<table>
<thead>
<tr>
<th>Exercise condition</th>
<th>Glut Med % MVIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvic drop</td>
<td>57</td>
</tr>
<tr>
<td>WB with flexion left hip abd</td>
<td>46</td>
</tr>
<tr>
<td>WB left hip abd</td>
<td>42</td>
</tr>
<tr>
<td>NWB sidelying hip abd</td>
<td>42</td>
</tr>
<tr>
<td>NWB standing hip abd</td>
<td>33</td>
</tr>
<tr>
<td>NWB standing flexed hip abd</td>
<td>28</td>
</tr>
</tbody>
</table>

* WB = Weight Bearing, NWB = Non-Weight Bearing, Abd = Abduction

### Table 3. Findings of Ayotte et al.5 Values are described as %MVIC, followed by rank in parentheses.

<table>
<thead>
<tr>
<th>Exercise condition</th>
<th>Glut Max %MVIC (rank)</th>
<th>Glut Med %MVIC (rank)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall squat</td>
<td>86 (1)</td>
<td>52 (1)</td>
</tr>
<tr>
<td>Mini-squat</td>
<td>57 (4)</td>
<td>36 (5)</td>
</tr>
<tr>
<td>Front step up</td>
<td>74 (2)</td>
<td>44 (2)</td>
</tr>
<tr>
<td>Lateral step up</td>
<td>56 (5)</td>
<td>38 (3)</td>
</tr>
<tr>
<td>Retro step up</td>
<td>59 (3)</td>
<td>37 (4)</td>
</tr>
</tbody>
</table>
To replicate a clinical setting, researchers chose to use visual analysis of movement to ensure proper exercise technique rather than an electrogoniometer or movement analysis software since both of these procedures are unlikely to be available in a clinic. To ensure proper exercise technique, each subject was allowed three practice repetitions prior to data collection and any necessary verbal and tactile cues by the instructing researcher. A description of each exercise may be found in Appendix A. After completing all exercises, the subject’s MVIC was reassessed to ensure electrodes had not been displaced during testing.

The equipment used for the conditions which required an unstable surface is the Core-Tex™ Balance Trainer™ (Performance Dynamics; San Diego, CA), a new piece of exercise equipment which is a platform mounted on a half-sphere atop a circular basin lined with ball bearings, creating an unstable and rapidly accelerating surface (Figure 2). The Core-Tex™ was developed to train a healthy fitness population; however, it may also be used to train individuals during rehabilitation in a clinical setting.

Data Analysis
All data were rectified and smoothed using a root-mean-square algorithm, and smoothed with a 50 millisecond (msec) time reference. Peak amplitudes were averaged over a 100 msec window of time, 50 msec prior to peak and 50 msec after the peak.
To determine MVIC, the middle 3/5ths time for each manual muscle test trial was isolated and the peak value determined. The highest peak value out of the three trials was recorded and determined to be the MVIC.

In order to establish %MVIC for each exercise performed by an individual subject, data were collected for the last five repetitions of each exercise. If the EMG data were clearly cyclic, the middle three repetitions were analyzed. If it was difficult to determine when a repetition started and stopped on visual analysis of EMG data, then the middle 3/5ths of the total time to perform the five repetitions was analyzed. The highest peak out of the three repetitions was then divided by MVIC to yield %MVIC for that individual.

To determine %MVIC values for rank ordering of exercises, the %MVIC for each muscle was averaged between all subjects for each exercise.

### RESULTS

Twenty-four subjects satisfied all eligibility criteria and consented to participate in the research study. Data from one subject were excluded due to faulty data from the EMG leads for both muscles, and data from another subject were excluded due to faulty data from the EMG lead for gluteus maximus only. There were a few other isolated instances of faulty data from EMG leads, in which case the subject’s data were excluded from analysis for that specific exercise. The number of subjects included in data analysis for each exercise can be referenced in Tables 4 and 5. Due to the advanced level of some of the exercises included in the current study, such as single limb bridge on unstable surface and side plank, some subjects were unable to successfully complete all exercises. In these instances, subject data were not included in data analysis for that specific exercise. Peak amplitudes,

<table>
<thead>
<tr>
<th>Exercise condition</th>
<th># Subjects Included for analysis</th>
<th>%MVIC Gluteus Medius</th>
<th>Rank Gluteus Medius</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side plank abd, DL down</td>
<td>21</td>
<td>103.11</td>
<td>1</td>
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<tr>
<td>Side plank abd, DL up</td>
<td>22</td>
<td>88.82</td>
<td>2</td>
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<tr>
<td>Single limb squat</td>
<td>22</td>
<td>82.26</td>
<td>3</td>
</tr>
<tr>
<td>Clamshell (Hip Clam) 4</td>
<td>23</td>
<td>76.88</td>
<td>4</td>
</tr>
<tr>
<td>Front plank with Hip Ext</td>
<td>23</td>
<td>75.13</td>
<td>5</td>
</tr>
<tr>
<td>Clamshell (Hip Clam) 3</td>
<td>22</td>
<td>67.63</td>
<td>6</td>
</tr>
<tr>
<td>Side-lying abd</td>
<td>23</td>
<td>62.91</td>
<td>7</td>
</tr>
<tr>
<td>Clamshell (Hip Clam) 2</td>
<td>22</td>
<td>62.45</td>
<td>8</td>
</tr>
<tr>
<td>Lateral step-up</td>
<td>21</td>
<td>59.87</td>
<td>9</td>
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<tr>
<td>Skater squat</td>
<td>22</td>
<td>59.84</td>
<td>10</td>
</tr>
<tr>
<td>Pelvic Drop</td>
<td>23</td>
<td>58.43</td>
<td>11</td>
</tr>
<tr>
<td>Hip circumduction, stable</td>
<td>23</td>
<td>57.39</td>
<td>12</td>
</tr>
<tr>
<td>Dynamic Leg Swing</td>
<td>22</td>
<td>57.30</td>
<td>13</td>
</tr>
<tr>
<td>Single limb deadlift</td>
<td>22</td>
<td>56.08</td>
<td>14</td>
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<td>Single limb bridge, stable</td>
<td>22</td>
<td>54.99</td>
<td>15</td>
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<tr>
<td>Forward step-up</td>
<td>22</td>
<td>54.62</td>
<td>16</td>
</tr>
<tr>
<td>Single limb bridge, unstable</td>
<td>20</td>
<td>47.29</td>
<td>17</td>
</tr>
<tr>
<td>Clamshell (Hip Clam) 1</td>
<td>22</td>
<td>47.23</td>
<td>18</td>
</tr>
<tr>
<td>Quadruped hip ext, DOM</td>
<td>23</td>
<td>46.67</td>
<td>19</td>
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<tr>
<td>Gluteal squeeze</td>
<td>23</td>
<td>43.72</td>
<td>20</td>
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<td>Hip circumduction, unstable</td>
<td>23</td>
<td>37.88</td>
<td>21</td>
</tr>
<tr>
<td>Quadruped hip ext, non-DOM</td>
<td>23</td>
<td>22.03</td>
<td>22</td>
</tr>
</tbody>
</table>

Table 4. Results for Gluteus Medius recruitment, %MVIC and rank for all exercises.
expressed as %MVIC for gluteus medius and gluteus maximus, are rank ordered in Tables 4 and 5. Five of the exercises produced greater than 70%MVIC of the gluteus medius muscle. In rank order from highest EMG value to lowest, these exercises were: side plank abduction with dominant leg on bottom (103%MVIC), side plank abduction with dominant leg on top (89%MVIC), single limb squat (82%MVIC), clamshell (hip clam) progression 4 (77%MVIC), and font plank with hip extension (75%MVIC). Five of the exercises recruited gluteus maximus with values greater than 70%MVIC. In rank order from highest EMG value to lowest, these exercises were: front plank with hip extension (106%MVIC), gluteal squeeze (81%MVIC), side plank abduction with dominant leg on top (73%MVIC), side plank abduction with dominant leg on bottom (71%MVIC), and single limb squat (71%MVIC). Table 6 displays the exercises that

<table>
<thead>
<tr>
<th>Exercise condition</th>
<th># Subjects Included for analysis</th>
<th>%MVIC Gluteus Medius</th>
<th>%MVIC Gluteus Maximus</th>
<th>Rank Gluteus Maximus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front plank with Hip Ext</td>
<td>22</td>
<td>106.22</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Gluteal squeeze</td>
<td>22</td>
<td>80.72</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Side plank abd, DL up</td>
<td>22</td>
<td>72.87</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Side plank abd, DL down</td>
<td>21</td>
<td>70.96</td>
<td></td>
<td>4</td>
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<tr>
<td>Single limb squat</td>
<td>22</td>
<td>70.74</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Skater squat</td>
<td>21</td>
<td>66.18</td>
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<td>Lateral step-up</td>
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<td>63.83</td>
<td></td>
<td>7</td>
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<tr>
<td>Quadruped hip ext, DOM</td>
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<td>59.70</td>
<td></td>
<td>8</td>
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<tr>
<td>Single limb deadlift</td>
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<td>58.84</td>
<td></td>
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<tr>
<td>Forward step-up</td>
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<td>54.67</td>
<td></td>
<td>10</td>
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<td>Single limb bridge, stable</td>
<td>21</td>
<td>54.24</td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>Clamshell (Hip Clam) 1</td>
<td>22</td>
<td>53.10</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Side-lying abd</td>
<td>22</td>
<td>51.13</td>
<td></td>
<td>13</td>
</tr>
<tr>
<td>Single limb bridge, unstable</td>
<td>18</td>
<td>49.35</td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>Hip circumduction, stable</td>
<td>22</td>
<td>37.85</td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>Dynamic leg swing</td>
<td>22</td>
<td>33.65</td>
<td></td>
<td>16</td>
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<tr>
<td>Hip circumduction, unstable</td>
<td>22</td>
<td>28.87</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>Clamshell (Hip Clam) 3</td>
<td>22</td>
<td>26.63</td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>Clamshell (Hip Clam) 4</td>
<td>22</td>
<td>26.22</td>
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<td>19</td>
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<td>Pelvic Drop</td>
<td>22</td>
<td>25.10</td>
<td></td>
<td>20</td>
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<tr>
<td>Quadruped hip ext, non-DOM</td>
<td>22</td>
<td>21.04</td>
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</tr>
<tr>
<td>Clamshell (Hip Clam) 2</td>
<td>22</td>
<td>12.36</td>
<td></td>
<td>22</td>
</tr>
</tbody>
</table>

Table 6. Top exercises for muscle activation of both gluteus medius and gluteus maximus (>70% MVIC).
produced greater than 70%MVIC for both gluteus medius and maximus muscles. These exercises included front plank with hip extension (75%MVIC, 106%MVIC), side plank abduction with dominant leg on top (89%MVIC, 73%MVIC), side plank abduction with dominant leg on bottom (103%MVIC, 71%MVIC), and single limb squat (82%MVIC, 71%MVIC) for gluteus medius and maximus respectively.

DISCUSSION
The main objective of this study was to examine muscle activity during common clinical exercises used to strengthen the gluteus medius and gluteus maximus muscles. This study sought to analyze and compare information reported in previous studies by Distefano, Bolga, and Ayotte regarding ranking of various therapeutic exercises using %MVIC. The secondary objective was to describe %MVIC for other commonly used therapeutic exercises not previously reported upon. The authors of this study chose to examine peak amplitude averaged over a 100 ms window, 50 ms prior to peak and 50 ms after the peak, during repetitions five, six and seven, the highest of which was converted to %MVIC. This methodology is similar to studies by both Distefano and Bolga. Ayotte et al. averaged EMG activity over a 1.5 sec window during the concentric phase of each exercise. Due to slight differences in data collection and data analysis between the current study, and studies conducted by Distefano, Bolga and Ayotte, interpretation of results and similarities across studies will predominantly address the sequence of rank order as opposed to absolute values for the %MVIC.

There were two exercises where %MVIC was found to be higher than MVIC, side plank abduction with dominant leg down (103%MVIC) for gluteus medius and front plank with hip extension (106%MVIC) for gluteus maximus. There are several possibilities as to why these findings may have occurred. One possibility is that subjects lacked sufficient motivation to perform a true maximal contraction during MVIC testing, despite the fact that verbal encouragement was given to all subjects during max testing of both muscles. Another possibility is that subjects were not able to truly give a maximum effort during the manual muscle test. Authors of previous research have reported that in order to obtain a true maximum contraction, it is necessary to superimpose an interpolated twitch, which is an electrically stimulated contraction, on top of the maximum voluntary contraction. Current research in electrophysiology is further examining this phenomenon with mixed results regarding sensitivity of various interpolated twitch techniques, differences in methodology, and interpretation of their results. Future researchers using MVIC for standardization across subjects should follow this research closely in order to ensure the most accurate methodology is used for establishing maximal voluntary muscle contractions. A final possibility is that with these exercises there was substantial co-contraction of the core musculature, which may have led to higher values than could be obtained during isolated volitional contraction. In the MMT positions used to establish MVIC the pelvis is stabilized against the surface of the table with relatively isolated muscle recruitment. In both of the above mentioned exercises, the pelvis does not have external support and higher EMG values could reflect increased activity due to an increased need for stabilization resulting in synergistic co-contraction. Future research may need to examine differences in muscle recruitment and activation patterns in exercises that test isolated muscle function versus ones that require core stabilization resulting in co-contraction.

Gluteus Medius
Table 7 depicts the top gluteus medius exercises determined by the authors of the current study as referenced to the exercises examined in studies performed by Distefano, Bolga, and Ayotte. The authors of the current study found highest %MVIC peak values for side plank abduction with dominant leg on bottom (103%MVIC), side plank abduction with dominant leg on top (89%MVIC), single limb squat (82%MVIC), clamshell progression 4 (77%MVIC), and front plank (75%MVIC) as outlined in Table 7. Four of the top five exercises were not previously examined by Distefano, Bolga, or Ayotte. All of these exercises exhibited greater than 70%MVIC, the peak amplitude necessary for enhancement of strength, suggesting they may have benefits for gluteus medius strengthening. However, these exercises are all very challenging and would not be appropriate for initial strengthening in patients with weak core musculature due to their high degree of difficulty and the amount of core stabilization required. The possible exception may be clamshell progression 4, due to the stabilization provided to the subject when lying on the floor to perform the
While the top exercises in this study produced the greatest peak amplitude EMG values, it is also important to consider functional demands and dosage when selecting an exercise for muscle training and strengthening, especially in early stages of rehabilitation of a weak or under-recruited muscle.

The top gluteus medius exercises from Distefano’s study were sidelying hip abduction (81%MVIC), single-limb squat (64%MVIC), and single limb dead lift (58%MVIC). With the exception of single limb squat, the current study found similar rank order with values of 63%MVIC, 82%MVIC, and 56%MVIC respectively. Of note, Distefano’s subjects performed the single limb squat to a predetermined knee flexion angle of approximately 30 degrees, while the current study had the subjects perform the exercise to a predetermined chair height of 47 cm. This difference in methodology may account for the difference in findings across the two studies. The methodology used by Distefano may allow for greater normalization, as squatting to a predetermined knee flexion angle allows for equal challenge to all subjects, whereas squatting to a predetermined height creates a greater challenge for taller subjects.

Bolga’s top exercise for gluteus medius was the pelvic drop (57%MVIC). The current study found a similar value at 58%MVIC, although this exercise was ranked 11th out of the 22 exercises evaluated. This exercise should not be discounted; however, as it is a functional training exercise for pelvic stabilization in single limb stance, and many gait abnormalities and lower extremity pathologies are the result of the gluteus medius muscle’s inability to properly and effectively stabilize the pelvis during single limb stance.

Bolga found sidelying abduction to have a value of 42%MVIC, which is significantly lower than the findings in either the Distefano or the current study. In general, qualitative movement analysis during performance of sidelying abduction reveals poor technique with frequent substitution using the tensor fascia lata muscle demonstrated through increased hip flexion during abduction, which may have accounted for the low value found in the Bolga study. Furthermore, subjects in both the Distefano and the Bolga study maintained the bottom leg in neutral hip extension and knee extension, while subjects in the current study were allowed to flex the bottom hip and knee in order to provide greater support and stabilization during abduction of the top leg.

Ayotte’s top exercise was the unilateral wall squat (52%MVIC), which is comparable to the single limb squat, ranking in the top three exercises in both the current study and in Distefano’s study, although the external stabilization provided in the unilateral wall squat should be considered. Ayotte ranked forward step-up (44%MVIC) higher than lateral step-up (38%MVIC), whereas the authors of the current study ranked lateral step-up (60%MVIC) higher than forward step-up (55%MVIC). It should be noted that subjects were allowed upper extremity external support during the exercise in Ayotte’s study which may

<table>
<thead>
<tr>
<th>Exercise condition</th>
<th>Current Study</th>
<th>Distefano</th>
<th>Bolga</th>
<th>Ayotte</th>
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<tr>
<td>1 Side plank abd, DL down</td>
<td>103</td>
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<td></td>
<td></td>
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<tr>
<td>2 Side plank abd, DL up</td>
<td>89</td>
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<td>3 Single Limb Squat</td>
<td>82</td>
<td>64</td>
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</tr>
<tr>
<td>4 Clamshell (Hip Clam) 4</td>
<td>77</td>
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<td></td>
<td></td>
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<tr>
<td>5 Front plank with Hip Ext</td>
<td>75</td>
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<tr>
<td>7 Side-lying abd</td>
<td>63</td>
<td>81</td>
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<td>38</td>
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<tr>
<td>9 Lateral step-up</td>
<td>60</td>
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<td></td>
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<tr>
<td>11 Pelvic Drop</td>
<td>58</td>
<td>57</td>
<td></td>
<td></td>
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<tr>
<td>14 Single limb deadlift</td>
<td>56</td>
<td>58</td>
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<tr>
<td>16 Forward step-up</td>
<td>55</td>
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<td>44</td>
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<tr>
<td>18 Clamshell (Hip Clam) 1</td>
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*Single-limb wall squat
account for these differences, along with differences in data analysis described previously.

### Gluteus Maximus

Table 8 depicts the top exercises for gluteus maximus of the current study. These include front plank with hip extension (106%MVIC), gluteal squeeze (81%MVIC), side plank abduction with dominant leg on top (73%MVIC), side plank abduction with dominant leg on bottom (71%MVIC), and single limb squat (71%MVIC). The top four exercises from the current study were not performed in other studies. Bolgla’s study did not include assessment of performance of the gluteus maximus so will not be included in the discussion below.

Distefano’s top exercises were single limb squat (59%MVIC), single limb deadlift (59%MVIC), and sidelying hip abduction (39%MVIC). Subjects performing these same exercises in the current study produced results of 71%MVIC, 59%MVIC, and 51%MVIC, respectively, demonstrating the same rank order of muscle activity as these exercises in the Distefano study. Bolgla’s study did not include assessment of performance of the gluteus maximus so will not be included in the discussion below.

Distefano’s top exercises were single limb squat (59%MVIC), single limb deadlift (59%MVIC), and sidelying hip abduction (39%MVIC). Subjects performing these same exercises in the current study produced results of 71%MVIC, 59%MVIC, and 51%MVIC, respectively, demonstrating the same rank order of muscle activity as these exercises in the Distefano study. The only differences in rank ordering between the current study and Distefano’s for gluteus maximus were between clamshell progression 1 and sidelying abduction; however, within each study there was less than 5%MVIC difference for each exercise when determining rank order (Table 8). As previously noted, differences in technique and substitution are common occurrences during the performance of sidelying abduction which may account for the differences found between the two studies.

Ayotte ranked forward step-up (74%MVIC) higher than lateral step-up (56%MVIC), whereas the current study ranked lateral step-up (64%MVIC) higher than forward step-up (55%MVIC). Again, differences could be attributed to variances in technique or the ability of subjects in Ayotte’s study to use external upper extremity support as well as differences in data analysis.

The low ranking for stable single limb bridge (11th) and unstable single limb bridge (14th) was somewhat surprising as both are common exercises used clinically for gluteus maximus strengthening. There were several instances of subjects reporting hamstring cramping during bridging on the unstable surface, which led the researchers to suspect substitution with the hamstrings during this exercise. The same may hold true for bridging on the stable surface, however there were fewer complaints. Future studies should examine muscle recruitment and activation patterns of gluteus maximus and the hamstrings during various bridging activities.

The effect of a subject’s attention to volitional contraction of a muscle during an exercise should also be considered. The gluteal squeeze was the only exercise where verbal cues were explicitly given to maximally contract the gluteal muscles while performing the exercise, which could possibly have contributed to its high ranking for performance by the gluteus maximus. Future research should examine the difference in amount, if any, noted in muscle recruitment when verbal instructions are given to concentrate on the muscle contraction while

<table>
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<th>Ayotte</th>
</tr>
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<tr>
<td>1  Front plank with Hip Ext</td>
<td>106</td>
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<td></td>
</tr>
<tr>
<td>2  Gluteal squeeze</td>
<td>81</td>
<td></td>
<td></td>
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<tr>
<td>3  Side plank abd, DL up</td>
<td>73</td>
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<tr>
<td>4  Side plank abd, DL down</td>
<td>71</td>
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<td></td>
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<tr>
<td>5  Single limb squat</td>
<td>71</td>
<td>59</td>
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<td>7  Lateral step-up</td>
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<tr>
<td>9  Single limb deadlift</td>
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<td>59</td>
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<td>10 Forward step-up</td>
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<td>12 Clamshell (Hip Clam) 1</td>
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</tr>
<tr>
<td>13 Side-lying abd</td>
<td>51</td>
<td>39</td>
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*Single-limb squat
performing the exercise versus no verbal instructions during performance. The effects of tone of voice, volume of cues, and frequency of verbal cueing are unknown.

CONCLUSION
Anderson and Fry have previously reported that higher %MVIC values with exercises correlate to muscle hypertrophy.20,22 By knowing the %MVIC of the gluteus maximus and medius that occurs during various exercises, the potential for strengthening these muscles can be inferred. Subsequently, exercises may be ranked to appropriately challenge the gluteus maximus and medius during rehabilitation. The authors of the current study found patterns within their results consistent with previous research published by Distefano and Bolgla.3,4 The authors conclude that differences in data collection and analysis as well as the use of external upper extremity support may have accounted for the differences noted between the current study and the study by Ayotte.5 One of the purposes of the current study was to provide a rank ordered list of exercises for the recruitment of the gluteus maximus and medius. These rank ordered lists may help form the basis for a graded rehabilitation program. For patients early in the rehabilitation process, the clinician should systematically determine which muscle they are wishing to strengthen and use less difficult (lower %MVIC) exercises. In order to maximally challenge a patient's gluteus maximus and medius, the authors recommend using a front plank with hip extension, a single limb squat, and a side plank on either extremity with hip abduction.

REFERENCES


APPENDIX A

1. Clamshell (hip clam) Progression: Each exercise is performed with the subject sidelying on the non-dominant side. (Figure 3)

   a. Progression 1 (upper left): Start position is sidelying with hips flexed to approximately 45 degrees, knees flexed, and feet together. Subject externally rotates the top hip to bring the knees apart for one metronome beat and returns to start position during the next beat.

   b. Progression 2 (upper right): Start position identical to progression 1; however, in this progression subject keeps the knees together while internally rotating the top hip to lift the top foot away from the bottom foot for one metronome beat, returning to the start position during the next beat.

   c. Progression 3 (lower left): The subject is positioned identical to progressions 1 and 2, but with the top leg raised parallel to the ground. The subject maintains the height of the knee while internally rotating at the hip by bringing the foot toward the ceiling for one beat and then returns to the start position during the next beat.

   d. Progression 4 (lower right): The subject is positioned the same as progression 3, but with the hip fully extended. As in progression 3, the subject maintains the height of the knee and internally rotates at the hip by bringing the foot toward the ceiling for one beat and returns to the start position with knee and ankle in line during the next beat.

2. Pelvic drop: Subject stands with dominant leg on the edge of a 5 cm box (right), and then lowers the heel of the non-dominant leg to touch the ground without bearing weight, for one beat (left). Subject returns foot to the height of the box while keeping the hips and knees extended for one beat. (Figure 4)
3. Sidelying abduction: Start with subject sidelying on non-dominant side. Subject flexes the hip and knee of the support side and then abducts the dominant leg to approximately 30 degrees while maintaining neutral or slight hip extension and knee extension with the toes pointed forward for a count of two beats up and two beats down. (Figure 5)

4. Side Plank with Abduction, dominant leg up: (Start with subject in a side plank position with dominant leg up. Subject is instructed to keep shoulders, hips, knees, and ankles in line bilaterally, and then to rise to plank position with hips lifted off ground to achieve neutral alignment of trunk, hips, and knees. The subject is allowed upper extremity support as seen
on left. While balancing on elbows and feet, the subject raises the top leg into abduction (right) for one beat and then lowers leg for one beat. Subject maintains plank position throughout all repetitions (Figure 6).

5. Side Plank with Abduction, dominant leg down: Exercise position is identical to Exercise 4 except on the opposite side. Subject is instructed to abduct the non-dominant uppermost leg for two beats and lowers leg for two beats. Subject maintains plank position throughout all repetitions.

6. Front Plank with Hip Extension: Start with subject prone on elbows in plank with trunk, hips, and knees in neutral alignment (left). Subject lifts the dominant leg off of the ground, flexes the knee of the dominant leg, and extends the hip past neutral hip alignment by bringing the heel toward the ceiling (right) for one beat and then returns to parallel for one beat. (Figure 7)

7. Single Limb Bridging on Stable Surface: Start with subject in hook-lying position (left). The subject is instructed to bridge on both legs by keeping the feet on the floor and raising hips off the ground to achieve neutral trunk, hip, and knee alignment for one beat. From this position, the subject extends the knee of the non-dominant leg to full knee extension while keeping the femurs parallel (right) for one beat, returns the non-dominant leg to the bridge position for one beat, and then lowers the body back to the ground for one beat (Figure 8).

8. Single Limb Bridge on Unstable Surface: Subject is positioned as in Exercise 7 and places the dominant foot in the center of the Core-Tex™ (left).
The subject performs the same sequence as above (right) while maintaining the disc of the Core-Tex™ in the center. (Figure 9)

9. Hip Circumduction on Stable Surface: The subject places the non-dominant leg on the outside of the base of the Core-Tex™ and stands to the side of the Core-Tex™ on the dominant leg (left). The subject performs a single limb squat while tracing the toe of the non-dominant leg on the outside of the Core-Tex™ base (right) in an arc for three beats, then traces the toe back to the start, while returning to a standing position for three beats. Subjects were allowed two-finger unilateral upper extremity support on the frame of the Core-Tex™ for balance assist. (Figure 10).

10. Hip Circumduction on Unstable Surface: In standing, the subject places the non-dominant foot on the outer edge of the Core-Tex™ and stands to the side of the Core-Tex™ on the dominant leg (left). The subject then performs a single limb squat on the dominant leg while drawing an arc with the non-dominant foot, extending the arc away from the subject for three beats (right). The subject then returns the foot to the
starting position by drawing the foot in, while returning to a standing position for three beats. Subjects were allowed upper extremity support as in Exercise 9. (Figure 11)

11. **Single Limb Squat**: Subject stands on the dominant leg, slowly lowering the buttocks to touch a chair 47cm in height for two beats and then extends back to standing for two beats. (Figure 12)
12. **Single Limb Deadlift**: Subject stands on the dominant leg and slowly flexes at the hip, keeping the back straight, to touch the floor with the opposite hand for two beats. Subject then extends at the hip to standing for two beats. Subjects were permitted to have knees either straight or slightly bent in the case that hamstring tightness limited subject’s ability to touch the floor. (Figure 13)

13. **Dynamic Leg Swing**: Subject is positioned in standing on the dominant leg, and then begins to swing the non-dominant leg (with the knee flexed) into hip flexion (left) and extension (right) at a rate of one beat forward and one beat backward. Subjects were instructed to move through a smooth range of hip motion and to not allow their trunk to move out of the upright position. (Figure 14)

14. **Forward Step-up**: Beginning with both feet on the ground, subject steps forward onto a 20cm step with the dominant leg for one beat. Subject then steps up with the non-dominant leg during the next beat. Subject then lowers the non-dominant leg back to the ground for one beat followed by the dominant leg during the next beat. (Figure 15)
15. **Lateral Step-up**: Subject stands on the edge of a 15cm box on the dominant leg and squats slowly to lower the heel of the non-dominant leg toward floor for one beat and then returns to start position during the next beat. (Figure 16)

16. **Quadruped Hip Extension**: In quadruped (left) the subject extends the dominant leg at the hip, while keeping the knee flexed 90 degrees, to lift the foot toward the ceiling (right) to achieve neutral hip extension for two beats and then returns the dominant leg to the start position for two beats. This exercise was repeated with the non-dominant leg and EMG values were recorded in order to measure activity as both the stabilizing and moving leg. (Figure 17)

17. **Skater Squat**: Subject stands on the dominant leg and performs a squat to a comfortable knee flexion angle for two beats down and two beats up with non-dominant leg extended at the hip and flexed at the knee. The torso twists during the squat. The toe of the non-dominant leg was permitted to touch the ground between repetitions. (Figure 18)

18. **Gluteal Squeeze**: In standing with feet shoulder-width apart, subject squeezes gluteal muscles for two beats and then relaxes for two beats. Subjects were instructed to maximally contract the gluteal musculature during the exercise.
ABSTRACT

Study Design: Resident’s Case Study

Background/Introduction: The reports of spinal accessory nerve injury in the literature primarily focus on injury following surgical dissection or traumatic stretch injury. There is limited literature describing the presentation and diagnosis of this injury with an unknown cause. The purpose of this case report is to describe the clinical decision-making process that guided the diagnosis and treatment of a complex patient with spinal accessory nerve palsy (SANP) whose clinical presentation and response to therapy were inconsistent with the results of multiple diagnostic tests.

Case Description: The patient was a 27-year-old female triathlete with a five month history of right-sided neck, anterior shoulder, and chest pain.

Outcome: Based on the physical exam, magnetic resonance imaging, radiographs, electrodiagnostic and nerve conduction testing, the patient was diagnosed by her physician with right sterno-clavicular joint strain and scapular dyskinesis and was referred to physical therapy. Care was initiated based on this initial diagnosis. Upon further examination and perusal of the literature, the physical therapist proposed a diagnosis of spinal accessory nerve injury. Intervention included manual release of soft tissue tightness, neuromuscular facilitation and sport-specific strengthening, resulting in full return to functional and sport activities. These interventions focused on neurological re-education and muscular facilitation to address SANP as opposed to a joint sprain and dysfunction, as initially diagnosed.

Discussion: Proper diagnosis is imperative to effective treatment in all patients. This case illustrates the importance of a thorough examination and consideration of multiple diagnostic findings, particularly when EMG/NCV tests were negative, the cause was not apparent, and symptoms were less severe than other cases documented in the literature.

Level of Evidence: Diagnosis, level 4

Key Words: Differential diagnosis, shoulder pain, spinal accessory nerve palsy, sterno-clavicular pain, triathlete
INTRODUCTION

Patients with peripheral nervous system injuries are commonly treated by physical therapists. A peripheral nerve injury is an injury to the nerve root or more peripheral area of a nerve. The presentation of a peripheral nerve injury may include motor loss in muscles innervated by the injured nerve, with or without sensory deficits. The etiology of peripheral nerve injuries includes traumatic events, most often from motor vehicle accidents, lacerations, stretch or compression, and iatrogenic factors.1

The spinal accessory nerve (SAN) is a peripheral nerve that can sustain injury by a traumatic blow, a severe stretch/traction, or laceration during surgery.2-4 The SAN is particularly vulnerable to injury because of its subcutaneous location3,5 as it courses through the posterior triangle of the cervical region which is bordered by the middle third of the clavicle, posterior border of the sternocleidomastoid (SCM), and the anterior portion of the upper trapezius.6 The SAN provides motor but not sensory innervation to the SCM and trapezius muscles.2,3 When there is an injury to the SAN, the clinical presentation is labeled spinal accessory nerve palsy (SANP). The presentation of SANP includes shoulder depression, scapular dyskinesis, and dysfunctional movement patterns of the neck and shoulder region caused by decreased strength of the ipsilateral upper, middle, and lower trapezius and sternocleidomastoid muscles.2,3,7,8

When an upper extremity peripheral nerve injury is suspected, diagnostic testing is frequently used to confirm if nerve impairment is present. Radiographs are often the first diagnostic test used to assess the cervical spine. Radiographic images are used to assess the cervical spine and shoulder complex for bony abnormalities that may contribute to peripheral nerve impairments, but are not appropriate for examining tissue other than bone. Magnetic Resonance Imaging (MRI) provides a high level of soft tissue differentiation; however, these images do not assess the functional status of a peripheral nerve so other additional studies are beneficial to completely diagnose nerve pathology.9 Electrodiagnostic studies are more useful for assessing neural pathology than imaging studies. Nerve conduction velocity (NCV) and needle electromyography (EMG) offer valuable information to the clinician regarding muscle innervation, the ability of a specific nerve to transmit neural activity, and the location of a nerve injury. When an injured nerve is tested over time, the tests may provide information regarding muscle re-innervation.10 Electrodiagnostic tests are recommended as the best tools to differentiate radiculopathy from a musculotendinous shoulder injury.9 Differentiating the tissue involved in the pathology can help the clinician in making a differential diagnosis and choosing appropriate interventions. Unfortunately, despite suggestions to use EMG and NCV to detect a SANP6,8 authors describing the presentation and findings of SANP have reported inconsistent results of electrodiagnostic tests when assessing spinal accessory nerve palsy.2,11 The sensitivity and specificity of electrodiagnostic tests for detecting SANP specifically could not be found in the literature.

The ability to differentiate peripheral nerve injuries from local musculoskeletal injuries is imperative to optimize patient outcomes. The performance of a thorough examination and development of a differential diagnosis list, instead of relying on previous examinations and testing, is what supports the physical therapists ability to facilitate individualized treatment effectively. Since an injury to the SAN involves motor loss without sensory dysfunction, it is often difficult to clinically differentiate SANP from a musculoskeletal dysfunction. A false negative encountered in diagnostic testing makes proper diagnosis even more difficult. In addition, the reports of spinal accessory nerve injury in the literature primarily focus on injury following surgical dissection or traumatic stretch injury. There is limited literature describing the presentation and diagnosis of this injury with an unknown cause. However, by developing a comprehensive list of differential diagnoses and continually assessing patient presentation and response to interventions, physical therapists are ideally suited to make evaluative judgements that can lead to the proper physical therapy diagnosis and treatment of complex patients. Therefore, the purpose of this case report is to describe the clinical decision making process that guided the diagnosis and treatment of a complex patient with SANP whose clinical presentation and response to therapy were inconsistent with the results of multiple diagnostic tests.

CASE DESCRIPTION

The patient was a 27-year-old, left-handed, female nurse and avid triathlete. She had a five month
The patient described first noticing her symptoms 3 days after participating in a ninjitsu martial arts class. The symptoms included achy, muscular pain over the right side of her neck and superior aspect of her shoulder and sharp pain over her right anterior chest with movement. She could not remember a specific mechanism of injury but did report that she felt as though she strained her right shoulder and neck during the class. Despite her symptoms, she continued to train for upcoming triathlon competitions with a strenuous training plan, including at least one training session daily, which exacerbated her anterior chest and shoulder pain.

Due to the effect of pain and dysfunction on her training, the patient consulted with her primary care physician one month after the onset of her symptoms. Radiographs and a MRI were performed on her right shoulder within a week of this visit and were determined to be normal. However, the information gained from the MRI may have been limited since it did not image the cervical spine region which also is a potential source of shoulder complex symptoms. Her physician recommended that she cease activities that increased her pain and continue to self-monitor her symptoms. The patient was only partially compliant with this advice as she tried to maintain her training at a level as high as possible without pain.

Over the subsequent 2 months, the patient noted progressively increasing pain with work and training activities, increased asymmetry of her shoulder including depression of the shoulder and increased appearance of bony prominences, and further decline in her ability to train, most notably during swimming and resistance training. Therefore, she returned to her physician for a follow-up examination. After this visit, NCV and EMG studies were performed on her right cervical paraspinal muscles, serratus anterior, levator scapulae, and upper trapezius, from which normal findings were reported. The patient was then referred to a physician, an orthopedic specialist, for a second opinion. Radiographs and a MRI of the right shoulder were repeated and again reported as normal. She was diagnosed with scapular dyskinesis and a right sternoclavicular (SC) joint strain by the physician. Treatment included a local steroid/anesthetic injection to the sternoclavicular joint, which provided mild relief of her pain. Five months following initial onset of symptoms, the patient was referred to physical therapy (Figure 1).

Figure 1. Timeline of Events.
Examination

During the initial physical therapy examination, the patient complained of sharp anterior chest pain with lifting weights, reaching overhead, and performing push-ups or pull-ups. Pain with these activities was rated verbally at 7 on a 0 to 10 Numeric Pain Rating Scale (NPRS); 10 being the worst pain possible. The NPRS has a moderate to high test-retest reliability (0.67 to 0.96) and responsiveness. A 3 point change is needed to demonstrate true change in pain. Her training included swimming, and she also was greatly limited in the ability to lift her head out of the water to breathe, suggesting a deficit in combined cervical motions of extension, rotation and sidebending. Dull, achy right anterior shoulder and right-sided neck pain (rated at 0 to 4 or 5 out of 10 on the NPRS) was noted at rest. The location of her symptoms can be viewed in her initial pain drawing in Figure 2. The patient denied any sensory disturbance including numbness or tingling in the neck, shoulder, or upper extremity. She reported taking over-the-counter Ibuprofen for pain as necessary. The patient's goals were to regain her range of motion in her shoulder and neck and to be able to participate in daily and sport activities without pain.

The Disabilities of the Arm, Shoulder and Hand Questionnaire (DASH), is an upper-extremity-specific health-related, quality of life functional outcome measure. It is a point-based, subjective questionnaire filled out by the patient that addresses each of the three areas of the International Classification of Functioning, Disability and Health (ICF) model disease-based outcomes. It is used to assess difficulty in physical activities including upper extremity function, pain, weakness, stiffness, tingling, and impact on social and psychological health. The percent of disability is calculated with 0% reporting no dysfunction and 100% reporting maximal dysfunction. The DASH has been reported to have good test-retest reliability, validity, and responsiveness for the entire upper extremity. The minimal clinically important difference (MCID) for the DASH is approximately 10 points. The patient filled out the DASH questionnaire at her initial examination and during the progress in rehabilitation. Upon initial examination, the patient scored 21.7% functional disability and 100% disability in sport on the DASH.

Upon observation, the patient's gait appeared normal, and she demonstrated normal arm swing of her involved upper extremity during ambulation. Her posture was moderately impaired with a moderate forward head, forward shoulder positioning (right greater than left), and a decreased thoracic kyphosis. Her right shoulder was visually estimated to be depressed approximately 1.5 inches compared to the left shoulder. The right clavicle was in a position of anterior protrusion, with the sternal end superiorly positioned and the acromial end inferior to the left clavicle. According to definitions by Sahrmann, the right shoulder girdle was depressed and forward, and the scapula was downwardly rotated. There was moderate atrophy of her right upper trapezius muscle (Figures 3 and 4) and the right SCM.

![Figure 2. Initial Symptom Drawing.](image)

Figure 2. Initial Symptom Drawing.

![Figure 3. Patient Presentation Upon Initial Examination. Note right scapular position and muscular atrophy of Upper trapezius and Sternocleidomastoid.](image)
Shoulder complex flexion was 180 degrees on the left and 150 degrees on the right. Active abduction of the shoulder complex was 190 degrees on the left and 150 degrees on the right. Active shoulder flexion and abduction elicited pain at the right sternoclavicular joint. However, pain was not the active range limiting factor. Lack of strength limited the patient's active range of motion. Right shoulder complex passive ROM was equal to that of the left.

The upper quarter neurological examination revealed normal sensation to light touch throughout the upper extremities and upper quadrants and normal biceps, triceps, and brachioradialis reflexes. The general upper limb tension test (ULTT) and compression/distraction were both negative. Strength testing revealed notable weakness on the right (Table 2). Strength grades included 4/5 in right cervical sidebending, 4/5 in cervical rotation to the left, 4+/5 in cervical rotation to the right, 4/5 in right shoulder flexion and abduction. The right upper trapezius strength was 2+/5, right middle and lower trapezius were each 3+/5; while all three portions of the trapezius were 4/5 on the left.

Passive joint mobility testing revealed decreased mobility in the posterior direction for the patient's right glenohumeral and sternoclavicular joints. With spinal segmental mobility testing, concordant signs and symptoms were not reproduced.

Movement testing revealed scapular dyskinesis, notably decreased control of the right scapula on eccentric lowering of the right upper extremity from elevated positions of flexion and abduction. This movement pattern is consistent with a Type III Kibler classification, allowing for superior-medial prominence of the scapular border. At that time, there was no distinction made regarding the severity of the symptoms in flexion as compared to abduction motions, as dyskinetic movement was observed in both planes of movement. However, diagnosis is difficult using visual observation of the shoulder complex as a study previously demonstrated physical therapists correctly identifying shoulder movement classification only 57.5% of the time.

The patient's active range of motion was measured using a standard goniometer (Table 1). Active range of motion was limited for cervical sidebending to the right and rotation to the left, and for right shoulder complex flexion and abduction. Cervical rotation to the right was 70 degrees and 55 degrees to the left with compensatory movements of cervical sidebending and thoracic rotation to attempt full motion.

Palpation of the right sternoclavicular joint induced significant, sharp, localized pain. Muscular palpation included symptoms of tenderness throughout the right upper trapezius, decreased tissue mobility in bilateral suboccipital musculature, and bilateral cervical paraspinals. Although there was muscular tenderness, concordant signs and symptoms were not reproduced.

Figure 4. Patient Presentation: Posterior. Note right scapular position and muscular atrophy.

Table 1. Range of Motion, Initial Examination

<table>
<thead>
<tr>
<th>Motion</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Cervical Rotation</td>
<td>55°</td>
<td>70°</td>
</tr>
<tr>
<td>Active Shoulder Flexion</td>
<td>180°</td>
<td>150° with pain</td>
</tr>
<tr>
<td>Active Shoulder Abduction</td>
<td>190°</td>
<td>150° with pain</td>
</tr>
<tr>
<td>Passive Shoulder Internal Rotation</td>
<td>55°</td>
<td>55°</td>
</tr>
<tr>
<td>Passive Shoulder External Rotation</td>
<td>100°</td>
<td>95°</td>
</tr>
</tbody>
</table>

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Passive joint mobility testing revealed decreased mobility in the posterior direction for the patient's right glenohumeral and sternoclavicular joints. With spinal segmental mobility testing, the patient...
presented with decreased right sidebending and left lateral glides at the levels of C2-C6 and decreased joint play in the posterior-to-anterior directions throughout the thoracic segmental levels, when assessed using spring testing. The occipital-atlantal joint was also decreased in passive segmental flexion mobility.

The Hawkins-Kennedy impingement test, Empty Can resistance test, and Drop Arm test were administered to assess supraspinatus pathology. The apprehension test was used to rule out instability, while the Apprehension test, O’Brien’s, Speeds test were used to assist in identifying labral or acromioclavicular joint involvement. None of these tests were positive for their intended purpose, but all elicited pain at the SC joint.

**Assessment**

Significant physical therapy findings included anterior chest and SC joint pain upon palpation and with active movement. The patient demonstrated decreased shoulder complex active range of motion, scapular dyskinesis with elevation, atrophy of the right upper trapezius and sternocleidomastoid, and weakness of the cervical, glenohumeral joint, and scapular musculature. Cervical, glenohumeral, and sternoclavicular joint mobility was decreased and there was decreased muscle activation present in the upper trapezius, while the cervical paraspinals had increased tension. Functional activity limitations included a limitation of her occupational tasks and triathlon training requirements. Electrodiagnostic studies performed on this patient were reported to be negative for nerve involvement, and general upper extremity nerve tension testing was negative. Thus, the initial plan of care was developed to limit the dysfunctional movement of the SC joint and to increase mobility in the posterior direction where mobility was limited in order to decrease pain, improve cervical and glenohumeral active range of motion, and increase strength in the weak cervical and right upper extremity musculature, all to increase patient function.

During the first 4 treatment sessions, intervention included the following: ultrasound to assist with increasing posterior SC joint mobility; manual mobilizations to increase posterior SC joint mobility; posteriorly-directed taping to the SC joint to assist with normalizing arthrokinematic movement of the SC joint; and right shoulder complex strengthening exercises directed at the right scapulo-thoracic and right upper extremity musculature to improve functional reaching and lifting. During this initial treatment plan, outcomes were only mildly successful and the therapist surmised that the extent of the impairments suggested more than a SC joint sprain with scapular dyskinesis. The anterior neck pain and prominent SC joint on the affected side in this patient were consistent with SC joint sprain or subluxation.20 Palpation of the SC joint caused localized pain. Similarly, the pain at the SC joint was reproduced with all shoulder special tests, consistent with primary SC pathology. However, the therapist questioned the potential causes of the muscle atrophy and scapular dyskinesis. Hence, a working list of additional differential diagnoses was generated. This list included long thoracic nerve injury, cervical disc disease with radiculopathy, brachial plexitis, and spinal accessory nerve palsy. Subsequently, the possibility of each of these differential diagnoses in this patient was more thoroughly evaluated.

Patients with cervical disc disease with radiculopathy and brachial plexitis usually report pain in the cervical spine, as well as motor and sensory deficits in the upper extremity.21,22 The patient had no sensory deficits and a negative ULLT. The ULLT has a sensitivity of 97% and a specificity of 22%,23 therefore, it is an appropriate test to rule out cervical radiculopathy when negative.

Both long thoracic nerve injury and SANP may be caused by a stretch injury to the neck, traumatic blow to the neck, or by iatrogenic factors.5,6,8 However, due to the difference in neural innervation, these two pathologies present with differences in patient symptoms and impairments. The long thoracic nerve innervates the serratus anterior and the SAN innervates the trapezius and sternocleidomastoid muscles. Key findings with a long thoracic nerve injury include glenohumeral instability, true scapular winging, and pain in the neck, shoulder, and periscapular regions.2,5 Additional findings of long thoracic nerve injury include weakness with overhead activities, difficulty with elevation in the frontal plane, and scapular instability with flexion as the serratus anterior fails to stabilize the medial border of the
scapula on the thorax. In SANP, a constant ache across the shoulder is often noted, and downward rotation of the shoulder complex occurs secondary to the remaining tension of the levator scapulae and rhomboids with a lack of opposition of the trapezius. In a complete SAN injury, abduction often is limited to 90° secondary to lack of scapular stabilization and decreased ability to upwardly rotate the scapulae with the upper trapezius. Scapular dyskinesis occurs in abduction in SANP rather than flexion due to weakness in the middle and lower trapezius muscles.

The use of EMG and NCV are reported to be helpful in differentiating between SANP and a long thoracic nerve injury, however, it appears there are inconsistent EMG/NCV findings in patients with SANP. Therefore, even with the negative electrodiagnostic findings, the therapist suspected the possibility of a long thoracic and/or SAN involvement at the spinal level in addition to a SC joint sprain. This may have initially been caused by a mild traction injury in martial arts, followed by entrapment due to the reflexive tightness of the surrounding musculature. Important findings included scapular and cervical spine weakness, visual presentation of atrophied trapezius and SCM, and scapular dyskinesis. However, to differentiate between long thoracic nerve palsy and SANP, further examination and special tests were deemed necessary.

The Scapular Flip Sign is a clinical special test proposed to diagnose SAN pathology. This test is performed with the patient holding both arms at their side with elbows flexed to 90 degrees, holding a dowel rod in both hands, and externally rotating both shoulders against resistance. The test is considered positive when the lower and middle trapezi are unable to oppose the pull of the infraspinatus and posterior deltoid, causing the medial scapula to “flip” off of the thoracic wall. This test is different from the Push Up Test for serratus anterior weakness in that the positive Scapular Flip Sign is demonstrating a lack of middle and lower trapezius stabilization, and the Push Up Test demonstrates a lack of serratus anterior stabilization of the scapulothoracic joint. The Scapular Flip Sign has not been evaluated for specificity or sensitivity; however, in a case series of patients with SANP, the Scapular Flip Sign was positive in all 20 patients.

This test, although not specifically named is similarly described by Chan. The current patient demonstrated a positive Scapular Flip Sign on the affected extremity, as shown in Figures 5a and 5b.

Further examination revealed SCM weakness on the right (2+/5 on the right versus 4+/5 on the left). A closer look at the pattern of scapular dyskinesis revealed greater deficits in abduction as compared to flexion. With obvious muscle wasting of the trapezius and SCM, SC joint pain, anterior shoulder pain, shoulder drooping, a positive Scapular Flip Sign, and significant scapular dyskinesis primarily observed during abduction motions, spinal accessory nerve palsy with a secondary sternoclavicular joint sprain emerged as the likely diagnosis. However, it is probable that the injury was incomplete as the patient had partial
Intervention and Outcomes

If the SAN is injured iatrogenically or by a penetrating trauma, operative treatment is recommended. Conservative treatment is recommended for patients sustaining a SANP due to a traction injury \(^5\) or for those whose injuries are incomplete.\(^6\) Thus, conservative treatment was continued for this patient following reassessment. The physician was contacted at this point of re-examination, and was in agreement with the findings and treatment plan. For a patient who meets the criteria for conservative treatment, the prognosis for a patient to return to prior levels of functioning with manual nerve entrapment release, muscle re-education, and functional training is normally 4 to 6 months.\(^2\) This patient was initially examined in physical therapy approximately five months after the injury, but without treatment, she had not improved. The patient's presentation included a decreased ability to perform activities of daily living and decreased functional ability.

The initial physical therapy interventions included manual posterior mobilizations of the SC joint, tissue mobilizations to increase occipital-atlantal and cervical segmental mobility, and stabilization techniques to the SC joint to assist with normalizing right upper extremity movement and activities of daily living. After hypothesizing SANP as a possible working diagnosis, interventions were focused on improving soft tissue mobility of the muscles surrounding the posterior cervical triangle to release potential SAN entrapment, neuromuscular facilitation of the atrophied musculature, and strengthening of the muscles that allow for elevation and rotation of the right upper extremity. The goals of this treatment were to normalize dysfunctional postures and movements and to release the areas of possible SAN entrapment as it crosses the posterior triangle.

To increase the patient's ability to perform work and training activities, strengthening of the muscles that assist with performance of the limited movement patterns were initially taught and reinforced as, based on other studies, strength gains are thought to occur over 4-6 months.\(^2\) Strength training was used to maximize the use of the muscles surrounding the injury that would allow for the patient to perform her functional activities without significant pain or disability. The targeted muscles included the rotator cuff, deltoids, and serratus anterior to assist with glenohumeral elevation and upward rotation of the scapula for functional activities. The deep cervical stabilizing musculature and flexors also were trained to assist with head movements and assist the SCM in order to initiate cervical flexion and rotation.

Throughout the course of physical therapy intervention, neuromuscular retraining of the trapezius and SCM was necessary to initiate recruitment of these muscles secondary to the belief of diminished neural supply. Manual tapping and positioning of the patient's head was used to facilitate muscle activation. Once palpable muscular activation was evident with these techniques, facilitation was performed in more functional positions to mimic sport specific demands.

The patient attended her final physical therapy appointment approximately 6 months after the initial PT examination and approximately 11 months after injury. At that time, she had regained full active range of motion in her neck and shoulder, full strength in her cervical spine and right upper extremity, and returned to recreational and work activities without pain. The right scapulothoracic musculature, including right middle and lower trapezius, improved to 3+/5 with manual muscle testing. She was able to perform all weight lifting activities including bench press and overhead press, and ran the Pittsburgh Marathon in a personal record time, both without pain by May 2009, five months after the initiation of physical therapy. She was able to swim freestyle for 2 laps straight and able to perform 10, non-modified push-ups in a row. The patient also noted that she was now able to examine her backside in a mirror from both directions due to her gain in neck strength and mobility.

The DASH functional outcome measure at physical therapy termination revealed 9.2% functional disability and 31.25% sport disability, compared to her initial scores of 21.67% and 100%, respectively. Each of the changes in score exceeded the MCID for positive changes in functional outcomes on the DASH.\(^15\) All special tests were negative, except for the scapular flip sign, which remained positive at discharge.
DISCUSSION
Before a clinician can make a “physical therapy” diagnosis, a thorough examination and thoughtful evaluation is necessary. The Guide to PT Practice refers to the evaluation as a dynamic process. The clinician must thoughtfully consider all examination data and as re-evaluation occurs, initial decisions may be reconsidered, change, and/or evolve. To facilitate this process, a differential diagnosis list must be incorporated into the initial evaluation phase. Many pathologies appear similar and without examining all the possibilities, less obvious or less common diagnoses may be missed. This case problem illustrates both the importance of a careful differential diagnosis and constant re-evaluation using examination data.

The patient in this case came to physical therapy with a specific medical diagnosis of right SC joint sprain and a movement dysfunction diagnosis: scapular dyskinesis of non-specific etiology. The shoulder complex dysfunction and pain exhibited by this patient could have been caused by numerous pathologies making a thorough examination imperative. Upon reassessment, the initial differential diagnosis list included long thoracic nerve injury, SC joint strain, cervical disc disease with radiculopathy, brachial plexitis, and SANP. It is important to note that although the EMG and NCV findings were negative, a neurologic origin for this patient's impairments could not be definitively excluded. EMG and NCV findings should be considered along with physical examination to provide a diagnosis and are not independently diagnostic.

After careful consideration and re-examination, the working diagnosis of sternoclavicular joint sprain and long thoracic and/or SAN involvement was made. In an attempt to clarify the pathology, the therapist consulted with co-workers and searched the literature. At first glance, SANP and long thoracic nerve injuries can appear quite similar due to the involvement of the scapula. However, injury to the long thoracic nerve involves dysfunction of the serratus anterior muscle while injury to the SAN involves dysfunction of the trapezius and the SCM. An important distinguishing detail to this diagnosis is that in a long thoracic nerve injury, true scapular winging occurs primarily when the upper extremity is elevated in the frontal plane (abduction). In this patient, the scapular dysfunction was most prominent during arm abduction. This distinction helped differentiate between the diagnosis of SANP and a long thoracic nerve injury. However, as previously described, diagnosis is difficult using visual observation of the shoulder complex.

Kelley et al reported that identifying SANP can be difficult and, therefore, proposed the use of the Scapular Flip Test. This positive test, combined with the scapular dyskinesis observed during active range of motion, muscular atrophy, and drooping of the shoulder, led the therapist toward SANP as the final diagnosis.

It is unknown why the EMG and NCV testing was not positive for nerve injury in this case. The testing was performed approximately four months after the injury occurred (greater than the proposed 21 days for EMG/NCV testing). It is possible that operator error may have played a role, and the needle may have passed through the upper trapezius to an inner-vated supraspinatus muscle. Other cases described in the literature have reported negative nerve conduction test findings in patients with the diagnosis of SANP, as was the presentation in the current case.

A proper diagnosis guides treatment for optimal outcomes. In this case, once the SANP diagnosis was considered most likely, the treatment plan was modified and became more specific to address issues related to the nerve involvement. With partial function of the trapezius and SCM remaining, it is likely the palsy was incomplete. Therefore, treatment emphasized manual soft tissue treatment of involved muscles and mobilization of bony structures that could be creating tension or pressure on the nerve. Also important was facilitating activation of the affected musculature, and strengthening the surrounding musculature until the trapezii and SCM regained function. Based on the successful outcome of this patient, it appears that the differential diagnosis process was helpful in determining an appropriate diagnosis and effective treatment plan.

CONCLUSION
SANP is a rare and potentially easily missed diagnosis. This case illustrates the importance of a thorough
examination and considering multiple diagnostic findings, particularly when EMG/NCV tests were negative, the cause was not apparent, and symptoms were less severe than other cases documented in the literature. Although it appears the process used in this case was beneficial to guiding treatment, it cannot be generalized to all patients. It is feasible that the interventions may have been successful based on the signs and symptoms regardless of the identification of SANP. Also, it cannot be determined which of the interventions was most successful or if there was natural healing that occurred due to the passage of time. Further research is needed to evaluate the sensitivity and specificity of the Scapular Flip Test; as well as to examine the same parameters for electrodiagnostics when used for identifying SANP. Conservative interventions for SANP also need to be assessed for their effectiveness.

REFERENCES


ABSTRACT

Improving strength and power in the athlete who is being rehabilitated is a central focus of the sports physical therapist, particularly in the terminal phases of rehabilitation where the emphasis shifts to readiness to return to sport and sports performance enhancement. High load strength training and power training through plyometric exercises are two key components of performance enhancement programs. A current concept in the strength and conditioning literature that is relatively unknown in sports physical therapy is postactivation potentiation (PAP). Even though we have limited data and there may be limited application of the concept of PAP for the sports physical therapist, awareness of this phenomenon is important nonetheless. The purpose of this clinical commentary is to introduce the sports physical therapist to the concept of PAP.

Key Words: complex training, power training, postactivation potentiation, strength training
INTRODUCTION
In the terminal phases of rehabilitation, the focus of rehabilitation tends to shift from restoration of impairments and functional limitations to return to sport and improving athletic performance. Once effusion has been minimized or eliminated, range of motion and strength have been restored, and the athlete has successfully completed a functional progression, specific return to sport activities commence in order to maximize performance potential. Prior to unrestricted participation in sports, improvements in an athlete's strength, power, and speed are common goals for the sports physical therapist which are important to address in the rehabilitation plan. During this stage, there is often collaborative effort between strength and conditioning staff as well as the athletic training staff due to the transition from a mindset of rehabilitation to that of return to sport and sport-specific performance. Therefore, it is imperative that the sports physical therapist be familiar with terms and training methodologies that may be implemented during this stage of rehabilitation.

Several methods exist to increase strength and power in the athlete. Strength is the ability of the muscle to exert force or torque at a specified or determined velocity,\(^1\) while power is defined as work per unit of time (force times distance divided by time) or as force times velocity (distance x time).\(^1\) Traditional weight training with relatively heavy loads (80-90% of 1 RM) for relatively few repetitions (4-8 repetitions) has shown the ability to improve an athlete's strength and is reported to enhance power to a greater extent than light loads.\(^2,3\) Plyometric training alone has been advocated as a means to improve muscular power and rate of force development (RFD) as compared to traditional weight training techniques, leading to improvements in dynamic athletic performance such as sprinting and jumping. Advocates have stated that plyometrics are a potential method used to bridge the gap between strength and power training methods.\(^4\)

Rate of force development is the rate at which strength increases, or the rate at which force can be produced.\(^5\) RFD is the single most important neural adaptation for the majority of athletes.\(^6\) Training programs dedicated to the development of power require both high-force training and high-quality power movements in which time and the rapidity of movements play a vital role in the quality of the exercise.\(^7\) Recently, a concept known as post-activation potentiation (PAP) has surfaced as a means to maximize acute power development in athletes. While it is not known yet at this time if there are any positive affects other than an acute increase in power, if the concept is more appropriate than using plyometrics alone, or if it has any application in sports rehabilitation, it is nonetheless important that the sports physical therapist be familiar with the term as well as the concept behind its application. The purpose of this commentary is to introduce the reader to the PAP concept which is common in strength and conditioning literature, but a likely unknown in sports physical therapy. Given that the sports physical therapist is often actively involved in the long-term training regimens of athletes, an understanding of the concept is warranted.

POST-ACTIVATION POTENTIATION
Originally defined by Robbins,\(^8\) PAP is a phenomenon by which the force exerted by a muscle is increased due to its previous contraction. Post-activation potentiation is a theory that purports that the contractile history of a muscle influences the mechanical performance of subsequent muscle contractions. Fatiguing muscle contractions impair muscle performance, but non-fatiguing muscle contractions at high loads with a brief duration may enhance muscle performance.\(^9\) The peak torque of an isometric twitch in skeletal muscle is transiently increased after a brief maximum voluntary contraction.\(^10,11\) Thus, PAP is the increase in muscle force and rate of force development (RFD) that occurs as a result of previous activation of the muscle,\(^12,13\) as well as the force and power of evoked high velocity shortening contractions, and the maximum velocity attained by evoked shortening contractions under load. In other words, excitation of the nervous system produces an increase in contractile function due to a heavy load conditioning stimulus.\(^14\) The most common indicator of PAP is increased evoked isometric twitch force observed following an evoked isometric tetanic contraction.\(^12\)

PAP is typically induced from maximum voluntary contractions, but has also been induced by velocity-controlled maximal voluntary concentric and eccentric contractions, as well as induced by submaximal isometric contractions.\(^12\) In a set of weightlifting exercises, the alternating submaximal concentric
and eccentric contractions may induce PAP, but the presence and extent of PAP produced by weight lifting exercise has not been determined.12

There are two proposed mechanisms of PAP. The first is the phosphorylation of myosin regulatory light chains, which renders actin-myosin more sensitive to calcium released from the sarcoplasmic reticulum during subsequent muscle contractions.13,15-17 As a result, the force of the each successive twitch contraction is increased. The second is that strength training prior to plyometric exercises causes increased synaptic excitation within the spinal cord, which in turn results in increased post-synaptic potentials and subsequent increased force generating capacity of the involved muscle groups.18 The most important muscle characteristic affecting the magnitude of PAP is fiber type, with the greatest potential for enhanced PAP in muscles with the highest proportion of Type II fibers,15,19,20 Further, PAP is greater in muscles with the shortest twitch contraction time.17,19,21,22 Based on muscle fiber type, athletes who perform in maximal intensity activities that depend on Type II muscle fibers (i.e. sprinting, weightlifting, throwing, jumping) would also show the greatest PAP in muscles involved in their sports performance.23

A method that the sports physical therapist can use to implement the concept of PAP for potential acute increases in power is through utilization of complex training. Complex training alternates biomechanically similar high-load weight training with plyometric exercises, set for set, in the same workout.24 Essentially, complex training involves pairing a high force activity with a high power activity. For example, the athlete may perform a high-load back squat followed by a countermovement jump or box jumps.

There is evidence supporting the utilization of complex training,25-27 although there is also evidence suggesting otherwise.29 At this time however, to the author's knowledge, there are no studies utilizing complex training in rehabilitation, nor is the scientific community certain that complex training impacts PAP or if it is simply a natural, acute phenomenon in the muscle. Sale has argued that PAP is more of a muscle phenomenon than something that can be trained or altered. It may be something that is simply an observation rather than something that can be used in training of an athlete.31 Previous studies using PAP have been performed on healthy, trained athletes. Comyns et al25 found that repeated exposure to complex training improved sprint performance in uninjured rugby players. Santos and Janiera28 found that complex training significantly improved squat jump, countermovement jump, medicine ball throw, and the Abalakov agility test (a 4x10-m agility test and a maximal vertical jump test) in young, uninjured male basketball players. Low- and high-load complex training was investigated by Matthews and others26 in basketball players' ability to perform a push-pass. Authors of the study suggest that high loads are needed to elicit a potentiation effect, and therefore loads nearing 85% of 1RM should be used to facilitate short-term power increases.26

A more recent study by Mitchell and Sale12 sought to determine if weight lifting induces PAP, indicated as potentiation of muscle twitch force. Researchers tested whether a five-repetition maximum (5-RM squat) both induced PAP and increased height of subsequently performed counter-movement jumps (CMJ). Subjects did five sets of CMJ both before and four minutes after one set of barbell back squats done with a 5-RM. Researchers observed a 2.9% increase in CMJ height four minutes after a 5-RM squat. This increase in CMJ was a significant enhancement of jump performance. These authors were the first to test the assumption that a weight lifting exercise induces PAP. Ultimately, the researchers concluded that PAP may have contributed to the increase in CMJ height, but the correlation between the magnitude of PAP and the percentage increase in CMJ height was not significant.

**DISCUSSION**

Clearly, much more information is needed on the concept of PAP before definitive conclusions can be made about its application as an actual training method or if it is simply a muscle phenomenon that causes an acute increase in power. More importantly, it is not known if it is appropriate for the recovering athlete due to the high loads used in both the high-load strength exercise as well as in the high-intensity plyometric exercises. The challenge for the sports physical therapist is to safely and effectively determine the load to use to utilize this concept appropriately. One-repetition maximum (1 RM) or a percentage of 1 RM is
For the sports physical therapist training the recovering athlete, the PAP concept may be most appropriately applied during functional training. The sports physical therapist could consider performing high-load leg presses early in a training session and then perform plyometric training exercises towards the end of the session in order to attempt to utilize the PAP concept. One could also use high load resistance activities prior to performing functional testing, in order to maximize performance in such tests as the single leg hop for distance, triple jump, 6 M timed hop, or vertical jump testing. However, it is not known if the short-term effects are carried over to future training sessions or if there is a long-term benefit. Plus, if short-term benefits were obtained from using the concept of PAP during functional testing, the sports physical therapist may not gain an accurate assessment of current status. Again, at this time, the above information is purely speculative.

If the sports physical therapist were to utilize this concept clinically, one possibility may be in helping to

Figure 1. High load step ups.

Figure 2. Walking lunges with dumbbells.

often used as the standard upon which to base the load used in strength and conditioning programs and literature, however, this 1 RM is being determined in healthy athletes. It is generally accepted that determining 1 RM in a recovering athlete is contraindicated because maximal efforts may cause a deleterious effect on healing or lead to further injury. Therefore, estimates of 1 RM or a 6 RM may be more appropriate. Several methods exist to potentially help the sports physical therapist provide adequate stimulus to obtain a PAP effect. The DeLorme technique, the Daily Adjusted Progressive Resistance Exercise (DAPRE), and the Oddvar Holten Diagram exist to provide a structured method to estimate load without performing a 1 RM. Furthermore, because the loads tend to be greater than 85% of 1 RM with the use of Olympic lifting bars or machines, equipment availability can also be a concern for the sports physical therapist. Olympic lifting requires Olympic bars, bumper plates, and extra space and resources that may not be available or in the budget. Furthermore, there is a tremendous learning curve with these movements.

For the sports physical therapist training the recovering athlete, the PAP concept may be most appropriately applied during functional training. The sports physical therapist could consider performing high-load leg presses early in a training session and then perform plyometric training exercises towards the end of the session in order to attempt to utilize the PAP concept. One could also use high load resistance activities prior to performing functional testing, in order to maximize performance in such tests as the single leg hop for distance, triple jump, 6 M timed hop, or vertical jump testing. However, it is not known if the short-term effects are carried over to future training sessions or if there is a long-term benefit. Plus, if short-term benefits were obtained from using the concept of PAP during functional testing, the sports physical therapist may not gain an accurate assessment of current status. Again, at this time, the above information is purely speculative.
Although based entirely on author opinion, resistance should begin with body weight to ensure appropriate technique is maintained and that the athlete has no subsequent effusion or pain. Based on studies using the concept of PAP, it is not currently advocated to perform the plyometric exercise with an external load. At this time, the author cannot support or repudiate this approach. Intuitively, in the rehabilitating athlete, bodyweight is most appropriate to limit risk of further injury and to ensure proper mechanics.

Rest periods between the strength exercise and the plyometric exercise in the available literature have been the topic of debate, but it appears that most benefit is obtained when at least an 8-12 minute rest period is completed prior to the plyometric exercise when performing it in a complex training format.33 A prolonged rest period with no activity is not practical for the sports physical therapist in most settings, and performing explosive exercises in a state of fatigue may impair performance.34

facilitate acute power increases in a unilateral lower extremity injury. Assuming a unilateral lower extremity condition (i.e. status post ACL reconstruction), the sports physical therapist may have the athlete perform exercises such as high-load step ups (Figure 1), walking lunges with dumbbells (Figure 2), single leg dumbbell squats (Figure 3), or utilize the single-leg press. These may be advocated over back squats or front squats because they enable the athlete to have unilateral emphasis to assist in the attempt to equalize strength among the extremities. Neitzel et al32 revealed that it can take several months after an ACL reconstruction to distribute weight evenly on both feet. Lunges, step ups, and single leg press may help mitigate the decrease in weight-bearing that may exist on the involved limb. To maximize strength, no more than 4-8 repetitions should be performed.23 Following the strength exercise, the athlete may then perform split jumps (Figure 4), box jumps, single leg countermovement jumps from a step or box (Figure 5), or single leg vertical jumps (Figure 6) for up to 6 repetitions.
CONCLUSIONS

Increasing strength and power production is a common goal for sports physical therapists. Postactivation potentiation is one of many concepts that exist that have shown promise in healthy, trained athletes to help improve acute increases in strength and power, although at this time, its application for the rehabilitating athlete is limited. Additionally, it is not known yet whether or not prolonged effects are realized or if it is purely an acute phenomenon. Although more research is needed both on healthy and recovering athletes, it is important that the sports physical therapist be cognizant of this unique training methodology in order to potentially provide optimum stimuli for return to athletic performance.

REFERENCES:
2. Schmidtbleicher D, Buerhle M. Neuronal adaptations and increase of cross-sectional area studying

The reader is referred to Table 1 for a sample workout utilizing PAP. It should be noted that both the table and the above suggestions are purely speculative. Note that resistance load (% RM) is not given and must be determined for each athlete. Clearly, further research is warranted in this area, particularly in the recovering athlete. Future research should determine appropriate rest periods between the strength and plyometric exercises, the appropriate load, and whether or not training history affects these variables.

<table>
<thead>
<tr>
<th>Resistance Exercise</th>
<th>Biomechanically-Similar Plyometric Activity</th>
<th>Rest Period (between resistance exercise and plyometric exercise)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Leg Press</td>
<td>Single Leg Vertical Jump 4 x 3 each leg</td>
<td>4-8 minutes, based on load or %RM</td>
</tr>
<tr>
<td>4 x 6-8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking Lunge 4 x 6 each</td>
<td>Split Jumps 4 x 3 each leg</td>
<td>4-8 minutes, based on load or %RM</td>
</tr>
<tr>
<td>DB Step Ups 3 x 6-8 each leg</td>
<td>Single Leg Countermovement Jump 3 x 3 each leg</td>
<td>4-8 minutes, based on load or %RM</td>
</tr>
</tbody>
</table>

Figure 5. Countermovement from step.

Figure 6. Single leg vertical jump.


ABSTRACT

Background and Purpose: Rehabilitation and strength and conditioning are often seen as two separate entities in athletic injury recovery. Traditionally an athlete progresses from the rehabilitation environment under the care of a physical therapist and/or athletic trainer to the strength and conditioning coach for specific return to sport training. These two facets of return to sport are often considered to have separate goals. Initial goals of each are often different due to the timing of their implementation encompassing different stages of post-injury recovery. The initial focus of post injury rehabilitation includes alleviation of dysfunction, enhancement of tissue healing, and provision of a systematic progression of range-of-motion and strength. During the return to function phases, specific return to play goals are paramount. Understanding of specific principles and program parameters is necessary when designing and implementing an athlete’s rehabilitation program. Communication and collaboration amongst all individuals caring for the athlete is a must. The purpose of this review is to outline the current evidence supporting utilization of training principles in athletic rehabilitation, as well as provide suggested implementation of such principles throughout different phases of a proposed rehabilitation program.

Evidence Acquisition: The following electronic databases were used to identify research relevant to this clinical commentary: MEDLINE (from 1950–June 2011) and CINAHL (1982–June 2011), for all relevant journal articles written in English. Additional references were accrued by independent searching of references from relevant articles.

Results: Currently evidence is lacking in the integration of strength and conditioning principles into the rehabilitation program for the injured athlete. Numerous methods are suggested for possible utilization by the clinician in practice to improve strength, power, speed, endurance, and metabolic capacity.

Conclusion: Despite abundance of information on the implementation of training principles in the strength and conditioning field, investigation regarding the use of these principles in a properly designed rehabilitation program is lacking.

Keywords: periodization, program design, rehabilitation, strength, training
BACKGROUND AND PURPOSE
Strength and conditioning is traditionally thought to exist only in the training of the healthy athlete, while rehabilitation is for the athlete who has been injured. Once the athlete completes their post-injury rehabilitation with the athletic trainer and/or sports physical therapist, they often then move onto the strength and conditioning coaches to resume their "weight room workouts" and re-integration with the team. The strength and conditioning coach, in consultation with the athletic trainer and/or sports physical therapist, uses an understanding of the proper technique and application of several types of exercise to develop a program to ready the rehabilitating athlete for competition.

Evidence supporting the implementation of strength and conditioning principles into such a program is currently sparse. Several authors have investigated both conservative and post-surgical interventions. While each of these studies have integrated specific strength and conditioning concepts, none have employed the entire spectrum of strength and conditioning as it applies to the rehabilitating athlete. The purpose of this clinical commentary, therefore, is to describe these strength and conditioning principles, and provide a suggested implementation of their use throughout the entire rehabilitation process, not just during the return to sport phase.

Assessment of the Athlete and the Post-Injury Training Program
Proper implementation of a post-injury training program requires assessment of the rehabilitating athlete, their sport, and the defined training program principles themselves (Figure 1). Periodic re-assessment of the athlete, as well as the program and its outcomes can provide the sports physical therapist the necessary information required to manipulate the various training program variables to achieve the desired goals. Specific training principles (Table 1) should be addressed when designing the athlete's program. The sports physical therapist should consider the phase of rehabilitation that the rehabilitating athlete is in when implementing such a program. The specific program parameters of strength, power, endurance, and hypertrophy must also be carefully considered and targeted when planning the program.

The requirements or demands of any given sport must be ascertained in order to determine how to properly manipulate the training variables throughout the

Figure 1. Program Design for the Rehabilitation Athlete.
these multiple measures. The assessment continuum should include a subjective report of functional ability, observation and examination of impairments, and functional performance testing as appropriate. Functional performance testing has previously been defined as using a variety of physical skills and tests to determine (1) one’s ability to participate at the desired level in sport, occupation, recreation, or to return to participation in a safe and timely manner without functional limitations and (2) one’s ability to move through as many as three planes of movement. Functional performance is assessed using nontraditional (e.g. beyond manual muscle and range-of-motion)
Training for muscle performance including strength, power, and endurance, requires different program design and does necessitates variability in exercise prescription (Table 2). Strength training typically involves a load/ intensity of 80-100% of the maximum amount of weight that the individual can lift one repetition (1 RM), utilizing approximately 1 to 6 repetitions.18-23 Power training, on the other hand, requires a primary component of velocity of movement. Therefore, since velocity is inversely proportional to the amount of load lifted, the load will have to be relatively lighter than loads utilized in strength training in order to accomplish the necessary velocity. Power training though does require a foundation of strength.

While strength and power training can require similar components of training, endurance training is fairly unique. Endurance training can involve many methods (circuit training, etc.) but the common theme is high repetitions with lighter loads.18-23 The relative work to rest ratio is the lowest amongst the primary three parameters of muscle performance. Endurance training can be a method to achieve hypertrophy training since moderate loads and repetition range of 8-12 is suggested for hypertrophy training.18,22,23

Traditional Training Program Parameters
Specifically training a muscle or group of muscles to achieve the desired goals of increased strength, power, endurance, and hypertrophy is paramount. The reader is advised to consult other sources18-20 for detailed information on training of these parameters, as it is also beyond the scope of this commentary to do so. General parameters will be discussed here.

### Table 2. Repetition Maximum Continuum

<table>
<thead>
<tr>
<th>Primary Parameter Trained</th>
<th>Repetition Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength and Power</td>
<td>0-6</td>
</tr>
<tr>
<td>High Intensity Endurance much greater than Strength and Power</td>
<td>6-12</td>
</tr>
<tr>
<td>Low Intensity Endurance greater than High Intensity Endurance</td>
<td>12-20</td>
</tr>
<tr>
<td>Low Intensity Endurance</td>
<td>20-30</td>
</tr>
</tbody>
</table>

### Table 3. Rest Period Continuum

<table>
<thead>
<tr>
<th>Primary Parameter Trained</th>
<th>Rest Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscular Power</td>
<td>5-8 minutes</td>
</tr>
<tr>
<td>Maximal Muscular Strength</td>
<td>3-5 minutes</td>
</tr>
<tr>
<td>Muscular Hypertrophy</td>
<td>1-2 minutes</td>
</tr>
<tr>
<td>Muscular Endurance</td>
<td>30-60 seconds</td>
</tr>
</tbody>
</table>

Phases of Injury Rehabilitation
Regardless of the type or region of injury, basic phases of rehabilitation have been described in the testing that provides qualitative and quantitative information related to specialized motions involved in sport, exercise, and occupations.13 The comprehensive assessment approach can be utilized to not only assess the rehabilitating athlete and their sport demands, but the success of the implemented program as well. If specific program parameter(s) (e.g. functional movement, strength, power, endurance, and/or hypertrophy) are determined to be deficient in the rehabilitating athlete during testing, the program can be modified to correct these deficiencies. Limitations demonstrated in fundamental movement patterns15,16 would require amelioration prior to placing emphasis on power training. Since it has recently been suggested that assessment of an individual’s overall functional ability is multifactorial14 complete description of functional assessment is beyond the scope of this clinical commentary. For additional suggestions on the implementation of the assessment of the athlete, the reader is referred elsewhere.13-17
Dependent on the injury status, whether surgery was involved, and the restrictions associated with the recovery, the duration of these phases will differ. There are some common characteristics, goals, precautions and criteria for progression to the subsequent phase. Described below and in Table 4 is a general outline of the various phases of rehabilitation based on multiple previous protocols, literature sources, as well as opinions of the authors. Criteria for progression, goals of each phase, and characteristics of each phase therefore are the authors' opinions based upon available protocols and past literature.

**Phase I, Immediate rehabilitation:** Characterized by tissue and/or joint inflammation and pain, disuse, detraining, loss of muscle performance, potential immobilization (dependent on injury), and initiation

| Table 4. Utilization of Non-Linear Periodization in Different Phases of Rehabilitation. |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| **Phase I Immediate Rehabilitation** | **Training Emphasis** | **Non-Linear Periodization Phase** | **Parameter Trained** | **Training with Team** |
| • Low intensity endurance of stabilizing muscles | I. Setting foundation with emphasis on muscle endurance | I. | I. Cardiovascular (CV) endurance training (e.g. stationary bike for injured UE or trunk, Upper body ergometer (UBE) for injured LE or trunk) |
| • Training of joint above and/or below for stability and endurance | | Monday: Endurance | Strength |
| | | Wednesday: Hypertrophy | Friday: Strength |
| **Phase II Intermediate Rehabilitation** | **Emphasis on increasing muscle size and continued strength training** | **Strength gain emphasis prior to transition to power training** | **Monday:** Hypertrophy |
| • Low to high intensity endurance of stabilizing muscles (dependent on their specific function) | II. | II. | Wednesday: Strength |
| • Progression from low to high intensity strength for muscles responsible for movement of affected area (dependent on contraindications and precautions, etc.) | | | Friday: Hypertrophy |
| | | | Monday: Monday: Strength |
| | | | Wednesday: | Strength |
| | | | Friday: | Strength |
| **Phase III Advanced Rehabilitation** | **Strength gain emphasis prior to transition to power training (short duration emphasis)** | **Begin transition to power** | **Interval training emphasis on proper energy system and incorporating total body movement patterns** |
| • Continued endurance emphasis for stabilizing muscles | II. | II. | | II. |
| • High intensity strengthening progressing | | | | |
| • Low to high intensity power progression of movement muscles (dependent on precautions, etc.) | | | | |
| | | | | |
| **Phase IV Return to Function** | **Continued progression of strength and power phase** | **Monday: Power** | **Sport related skills at game intensity progressed to normal practice and eventually return to game competition.** |
| • Continued as in phase III; with increased emphasis on clients’ functional requirements (i.e. power for jumping athletes; endurance for long distance running athletes, etc.) | I. | I. | | |
| | | Wednesday: Strength/Hypertrophy | Friday: Power | |
of tissue repair and/or regeneration. The primary goals to be addressed during this phase are protection of the integrity of the involved tissue, restoration of range-of-motion (ROM) within restrictions; diminishment of pain and inflammation, and prevention of muscular inhibition. Major criteria for progression to Phase II include: minimal pain with all phase I exercises, ROM≥75% of non-involved (NI) side, and proper muscle firing patterns for initial exercises.

**Phase II, Intermediate rehabilitation**: Characterized by continuation of tissue repair and/or regeneration, increased use of involved body part or region, decreased inflammation, and improved muscle performance. The primary goals to be addressed during phase II include: continued protection of involved tissue(s) or structures and restoration of function of the involved body part or region. Criteria for progression to Phase III include: close to full ROM/muscle length/joint play, and 60% strength of primary involved musculature when compared to the uninjured side.

**Phase III, Advanced rehabilitation**: Characterized by restoring normal joint kinematics, ROM, and continued improvement of muscle performance. The primary goals to be addressed during this phase are restoration of muscular endurance and strength, cardiovascular endurance, and neuromuscular control/balance/proproprioception. Criteria for progression to phase IV include: strength > 70-80% of non-involved (NI) side and demonstration of initial agility drills with proper form (e.g. avoidance of medial collapse of bilateral lower extremities, coordinated and symmetrical movement of all extremities, controlled movement of entire body).

**Phase IV: Return to function**: Characterized by activities that focus on returning the athlete to full function. The primary goals to be addressed during this phase are successful return to previous functional level in the athlete’s preferred activity, and prevention of re-injury.

**Designing a Training Program with Consideration for the Injured Athlete Needs**

**Analysis of Training Program**

In order to properly design a patient and sports specific rehabilitation program, a needs analysis should be performed.36 Performing a comprehensive analysis (Recall Figure 1), investigating such factors as the physiological and biomechanical requirements of a sport is required when designing the program. Components of a needs analysis include a general biomechanical analysis of the sport which rehabilitating athlete participates in, an analysis of the energy sources utilized in the sport, and an analysis of the common injury sites and patterns for the sport.36 Furthermore, an appropriate physiological analysis allows the clinician to devise a program that addresses specific strength, range of motion, flexibility, power, endurance, and speed requirements for any given sport. For example, an American football player needs more muscle size and strength than a cross-country athlete or a soccer player. Only by addressing these requirements specifically will an athlete be successful in returning to their sport or activity. Next, a biomechanical analysis is required to choose training activities that develop the athlete in a manner most specific to the sport. Specificity of training is a foundation of both functional and resistance training programs.18 It is the authors opinion that the sports physical therapist should be well-versed on injury patterns that are present in the sport in which the rehabilitating athlete is participating to ensure that prevention strategies are included. For example, female soccer and basketball players have demonstrated a higher risk for anterior cruciate ligament ruptures than athletes who participate in other sports.37-41 Likewise, American football lineman and gymnasts are at an increased risk for spondylolysis and spondylolisthesis compared to athletes in other sports.42-45 Each of these examples shows how training programs for the rehabilitating athlete should be specifically designed to accommodate each individual athlete’s needs to maximize performance and avoid subsequent injury. The reader is directed to Table 5 for an illustration of these concepts.

**Assessment of Rehabilitating Athlete’s Strengths and Weaknesses**

Assessment of each rehabilitating athlete’s strengths and weaknesses can be a complex undertaking. As previously mentioned, proper assessment of an athlete’s functional capacity is multi-factorial, involving multiple variables.14 Along with the assessment of the rehabilitating athlete’s strengths and weaknesses, knowledge of their training history/status, injury
Exercise selection is a critical program principle for which the clinician should account. Multi-joint exercises are exercises that involve many muscle groups in one exercise. Examples of multi-joint exercises include squats, deadlifts, cleans, bench presses, and push jerks. Typically, these exercises are done first in the training session because they are the most fatiguing, but also because they are recommended most for increasing muscle and bone strength. The other type of exercise is known as supplementary, or isolation exercises. Examples of isolation exercises include front
raises, lateral raises, and knee extensions. Since these isolation exercises are primarily single joint-single plane exercises, they are a good choice for the untrained or inexperienced athlete. Ultimately, though, the experienced athlete will require several multi-joint exercises in their program in order to be successful.

Progression to multi-joint exercises involves more instruction and greater time to practice in order for the athlete to establish the necessary coordination to properly execute the exercise safely and effectively. Performing large muscle mass, multi-joint exercises early in the workout has been shown to produce significant elevations in anabolic hormones. This type of anabolic response may potentially expose smaller muscles (such as those in the affected area) to a greater anabolic response than that resulting from only performing small muscle exercises.

**Availability of Training Equipment**

A lack of certain equipment necessitates changes or does not allow the performance of some exercises. In the context of free weights, lack of floor or ceiling space may hamper lifts that could involve dropped weights or pushing weights overhead. For example, many Olympic lifts performed overhead (i.e. snatch, jerks) are performed with bumper plates that bounce on the ground to promote athlete safety if a lift is missed, or if maximal lifts are attempted. In any of these cases, the bar is often dropped to the floor where it bounces and could potentially injure others. Some machines may not be multi-dimensional enough to be sport-specific for the rehabilitating athlete, so the clinician will need to supplement training programs with appropriate exercises. For example, when the rehabilitating athlete needs to perform a chest press motion, it may be more appropriate to use the dumbbell or barbell bench press than a weight machine. These lifts, although utilizing the same musculature, require the athlete to make adjustments to complete the lift given that the axis of movement is not fixed and may follow an unpredictable course compared to a seated chest press using a weight machine which only has one axis of movement.

**Training Frequency**

Training frequency ultimately depends on the volume and load of exercises, the type of movement (multi vs. single joint) that prevails throughout the workout, the training level of the athlete, the goals of training, and the health status of the athlete. Traditionally, resistance training on alternating days is encouraged in the early stages of training to ensure recovery, but frequency may increase with increased training experience. Previous authors have demonstrated insignificant differences in strength gains observed between training 1, 2, 3, or 5 days per week if the volume was kept constant. When near maximal resistances are used, more recovery time is advocated.

The sports physical therapist must also consider other concurrent training in which the athlete is involved. A young pitcher may not only be in season, but may also be working with a pitching coach once or twice a week in addition to resistance training. The frequency of training may need to be reduced to accommodate the athlete’s schedule of training in order to ensure that proper rest and recovery is achieved. Similarly, an increase in training frequency may be warranted if the athlete appears to be reaching a plateau or making minimal gains in one or more of the training parameters (e.g. strength, power, endurance).

**Exercise Order**

The ability to perform the desired load and volume of each exercise is dependent on proper order of exercise. Proper coordination of the integration of multi-joint and isolated strengthening exercises requires careful planning on part of the sports physical therapist. Each individual athlete’s physical condition, as well as their particular strengths and weaknesses will require consideration when designing the training program. Various methods of utilization of exercise order will be described.

Because multi-joint exercises require the most coordination, skill, and proper levels of energy, it is encouraged that they are performed first in the training session. For example, the bench press should be performed prior to tricep extensions. Since multi-joint lifts are the most fatiguing, the athlete is unlikely to obtain the maximum benefit of these exercises if the smaller muscle groups are fatigued from previous exercises. Pre-exhaustion is a training technique is a training technique in which a muscle is fatigued in a single-joint, isolated movement prior to performing
a multi-joint exercise involving the same muscle. An example of pre-exhaustion training is performing leg curls or leg extensions prior to a back squat or deadlift. The sports physical therapist may utilize this technique if they feel that the multi-joint movements are not completely developing the muscles in question or to help alleviate the effects of training boredom. To the author's knowledge, no studies exist utilizing pre-exhaustion as a training technique.

There are various methods of pairing exercises to challenge the athlete, alleviate boredom, and emphasize muscle endurance and hypertrophy. *Super setting* involves alternating agonists and antagonists with minimal rests between exercises. For example, a bench press followed by a seated row or a bicep curl followed by a triceps pushdown would be examples of super sets. *Compound setting* is performing two different exercises of the same muscle group in alternating fashion with little to no rest between exercises. Anterior lunges followed by squats or barbell bicep curls followed by alternating dumbbell curls are both examples of compound setting. Athletes in poor physical condition may find super setting, compound setting, or pre-exhaustion techniques too strenuous in the early stages of training.

Other methods to manipulate exercise order are to have an athlete perform upper and lower body exercises in an alternating fashion. The clinician can also have the athlete perform upper body push and lower body pull exercises alternatively, or vice versa. Lastly, the athlete can perform a "push-pull" routine. Here, the athlete can perform a front squat followed by a deadlift. Push-pull may involve agonists and antagonists, but may also include an upper body "push" exercise coupled with a lower body "pull", or vice versa. Collectively, these methods allow more exercises to be completed within a session and allow greater intensity of each exercise due to extended recovery of the each muscle group being worked. Plus, these methods help promote balance and symmetry of agonist-antagonist training.

**Rest Period & Resistance/Training Load**

Manipulation of all of the above training variables are applicable to the rehabilitating athlete, but it will require the sports physical therapist to design athlete specific programs, keeping the above principles in mind. Regardless of injury, it is advised that the athlete have at least 24 hours of recovery between sessions, and 48 hours in between sessions working the same muscle group. For a rehabilitating athlete who is seen only 1-2 times per week, a total body routine is advocated to maximize training balance. If training is done 4-5 days per week, a split routine is advocated by the authors of this review to allow proper recovery between muscle groups used. Regarding the athlete who is rehabilitating 3-5 days per week, the authors suggest activities on “off days” might include flexibility training, yoga, balance and proprioceptive exercises, or core/abdominal training.

Determining the training load and rest ratios requires careful consideration of the rehabilitating athlete’s sport and the body part or region to be trained. For example, muscles of the trunk are primarily slow twitch, type I muscle fibers that necessitate high repetition, low load endurance based training. Other, more explosive muscles that are prime movers, utilized in jumping (e.g. quadriceps and gastrocnemius) require strength based training programs, progressing to lower loads at explosive speeds, and plyometric type training for development of power.

Training load is usually determined with 1 RM testing in strength and conditioning. The use of 1 RM testing is often disadvantageous for the rehabilitating athlete as it requires a systematic progressive increase in maximum load lifting capability. Although this method is the most advantageous and accurate method of determining 1 RM, the use of estimating 1 RM and training load charts is advisable for these athletes. Other methods for determining training load include the DeLorme technique, the Daily Adjusted Progressive Resistance Exercise (DAPRE) technique, the OMNI-RES, or the Oddvar Holten method. These tables are intended to be used as a guide until the athlete has developed the neuromuscular capabilities that will allow them to safely and effectively test with heavier loads to more accurately determine their 1 RM. The use of such tables is but one method of determining load, as other methods have proven effective. Training volume is typically prescribed in terms of the number of repetitions per set, number of sets per session, and the number of sessions per week. The importance of training volume for maximal strength and hypertrophy gains
during early phases of resistance training has previ-
ously been demonstrated.57-59 Untrained, normal indi-
viduals were shown to experience maximal strength
gains with a mean training intensity of ≈12 RM, while
trained individuals demonstrated these gains with a
mean training intensity of ≈8 RM.59

The length of the rest period is dependent on the
training goal, the relative load lifted, the sport in
which the athlete participates, and the training sta-
tus of the athlete. The rest period is a primary deter-
minant of the overall intensity of a workout, as rest
period length is strongly related to the load lifted.18,21,60
The rest period length not only determines how
much of the adenosine triphosphate-phosphocrea-
tine (ATP-PCr) energy source is recovered,60 but
also how high post exercise lactate concentrations
become in the blood.47,61-63

Other training principles were outlined and defined
in Table 1. Additionally, Tables 2 and 3 provided
descriptions of training load and rest period sugges-
tions. Utilization of concepts and suggestions given in
these tables, as well as the outline provided in Figure
1 will provide the sports physical therapist the neces-
sary framework to design a proper training program
for the rehabilitating athlete. Integration of these
principles into a specific program is the next step.

**Integration of Training Principles and
Parameters into a Rehabilitation Program for
the Injured Athlete**

The previous sections offered suggestions regarding
multiple parameters and the opportunities for their
manipulation of these training principles for the
rehabilitating athlete, based on current evidence and
principles used with normal (uninjured) athletes.
Additionally, Table 1 defines periodization, as well
as the difference between linear and non-linear peri-
odization. The rehabilitating athlete may need to be
considered similar to the untrained category initially
with respect to the injured body part. Therefore, as
outlined in Table 4 the initial non-linear periodiza-
tion phase for the injured body part or region should
be an emphasis on higher repetitions and muscle
endurance/hypertrophy with a later initiation of
strength-based training. As the patient progresses
further in their rehabilitation, additional progression
into more aggressive strength training and power
training should be incorporated. Unlike linear peri-
odization, where the emphasis is on only one param-
eter (endurance, hypertrophy, strength, endurance),
non-linear periodization allows the clinician the abil-
ity to train more than one of these parameters at a
time, while still emphasizing one of them in a partic-
ular phase. Although the literature is lacking regard-
ing the utilization of types of periodization with the
rehabilitating athlete, the opinion of the authors of
this review is that the non-linear form of periodiza-
tion would most likely fit the rehab process in most
instances. Additionally, it is the authors’ suggestion
that the rehabilitating athlete continue with some
form of training with their team. Table 4 also offers
ideas on how to integrate the rehabilitating athlete
into team training components. This is a general
framework upon which the reader can build and
individualize a program specific to the needs of each
rehabilitating athlete.

As an alternative to non-linear periodization previ-
ously described, a rehabilitation program could be
constructed using short duration linear periodiza-
tion. Utilizing a short duration linear program would
require initial emphasis on high volume and low
intensity (endurance and/or hypertrophy phase).
Progression into the strength/power phase and
eventually to the power phase at end stage rehabili-
tation would then occur. Once again, the authors of
this commentary assert that non-linear periodiza-
tion may prove to be a more advantageous method
of program design for the rehabilitating athlete as it
affords implementation of multiple variables into
the different phases throughout the rehab program.

**CONCLUSION**

Strength and conditioning principles and training
parameters are a necessary component of the deci-
sion making and tailoring of any rehabilitation pro-
gram. This is especially important in the rehabilitation
and full return to function of an injured athlete. The
sports physical therapist implementing such pro-
grams should be cognizant of each the components
and variables for the rehabilitation program of an
athlete. Currently the literature has little to offer
regarding of the integration of strength and condi-
tioning concepts into the rehabilitation of the injured
athlete. The benefit of integration of these training
principles during the rehabilitation of an injured
athlete, although intuitive for best practice, remains elusive. Future studies should investigate the extent of the relationship between strength and conditioning principles and their integration into a rehabilitation program for the rehabilitating athlete. Determining how integral a role these training principles play for athletic rehabilitation is long overdue.

REFERENCES


52. Knight KL. Quadriceps strengthening with the DAPRE technique: case studies with neurological


ABSTRACT

Cervicogenic headache (CGH), as the diagnosis suggests, refers to a headache of cervical origin. Historically, these types of headaches were difficult to diagnose and treat because their etiology and pathophysiology was not well-understood. Even today, management of a CGH remains challenging for sports rehabilitation specialists. The purpose of this clinical suggestion is to review the literature on CGH and develop an evidence-led approach to assessment and clinical management of CGH.

Key Words: Headache, neck pain, muscle imbalance

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BACKGROUND AND DIAGNOSIS

Cervicogenic headaches (CGHs) pose a challenge for many sports physical therapists because the head pain results from somewhere other than the head: the cervical spine. Interestingly, CGHs are one of the most common types of headache in weight-lifting athletes. Patients who have sustained whiplash or concussion injuries with resulting neck pain sometimes develop CGH. In fact, headaches developing 3 months or more after concussion are generally not caused by brain or head injury, suggesting a possible cervical spine etiology.

The International Headache Society published their *International Classification of Headache Disorders 2nd edition*, identifying 14 different types and sub classifications of headaches. There are 2 basic categories of headaches, primary and secondary. Primary headaches include those of vascular origin (cluster and migraine headaches) as well as those of muscular origin (tension-type headaches). Secondary headaches result from another source including inflammation or head and neck injuries. Norwegian physician Dr. Ottar Sjaastad coined the term, “cervicogenic headache” in 1983 by recognizing a sub-group of headache patients with concomitant head and neck pain; therefore, CGHs are considered “secondary headaches.”

The diagnostic criteria for CGH include headache associated with neck pain and stiffness. Cervicogenic headaches are unilateral, starting from one side of the posterior head and neck, migrating to the front, and sometimes are associated with ipsilateral arm discomfort. Sjaastad et al identified another type of CGH with bilateral head and neck pain, aggravated by neck positions and specific occupations such as hair-dressing, carpentry, and truck/tractor driving. The neck pain precedes or co-exists with the headache, and is aggravated by specific neck movements or sustained postures. Vincent described several factors to differentiate CGHs, including:

- Unilateral pain with a facet ‘lock’ irradiating from the back of the head
- Evidence of cervical dysfunction presenting during manual examination
- May occur with trigger point palpation in the head or neck
- Aggravated by sustained neck positions
- Normal imaging

Because the diagnosis of CGH is relatively new, its particular etiology remains unclear. Sjaastad and his colleagues suggested that CGH is a “final common pathway” for pain generating disorders of the neck. Bogduk has proposed that the pathophysiology of CGH results from a convergence of sensory input from the upper cervical spine into the trigeminal spinal nucleus, including input from:

- Upper cervical facets
- Upper cervical muscles
- C2-3 intervertebral disc
- Vertebral and internal carotid arteries
- Dura mater of the upper spinal cord
- Posterior cranial fossa

The trigeminal pathway theory is somewhat supported by the fact that injection of the greater and lesser occipital nerves with steroids decrease headaches by blocking the trigeminal relay. Furthermore, Chua and colleagues recently reported impairments of sensory testing of the head in CGH patients compared to patients with neck dysfunction without headache. They concluded that the pathophysiology of CGH includes central sensitization of pain, likely from the trigeminal spinal nucleus.

Approximately 47% of the global population suffers from a headache, and 15-20 percent of those headaches are cervicogenic. Recently, CGHs were estimated to affect 2.2% of the population. Epidemiological researchers suggest a higher prevalence of headache in adults with neck pain. Females seem more predisposed to CGHs affecting 4 times as many women as men. Since CGHs commonly affect women, it is important to consider menstruation and hormonal shifts as a contributor to headaches. Menstrual-type headaches often occur 2 days before menstruation and last until the last day of the cycle. These headaches are usually migraine-type, but may be cervicogenic as well.

Migraine or tension-type headaches can also present with neck pain, further complicating differential diag-
nosis; in fact, some migraine patients experience more neck pain than nausea.\textsuperscript{21} Up to 44\% of CGH patients may have temporomandibular joint (TMJ) issues as well.\textsuperscript{22} Sports physical therapists should perform a comprehensive assessment of the neuromusculoskeletal system in patients with chronic headaches.

As with any differential diagnosis, it is important to first identify any “red flags” associated with headaches that may be a symptom of a serious condition. Patients with vertebral artery dissection present with concomitant headache and neck pain,\textsuperscript{23} so it is critical to rule out that condition in patients with headache and neck pain first. Red flag symptoms requiring further medical evaluation include:

- Headaches that are getting worse over time
- Sudden onset of severe headache
- Headaches associated with high fever, stiff neck, or rash
- Onset of headache after head injury
- Problems with vision or profound dizziness

Radiological examination is of limited value in diagnosing CGHs. Coskun and colleagues\textsuperscript{24} found that nearly half of CGH patients as well as asymptomatic subjects had bulging cervical discs. The most important clinical finding to diagnose CGH is impairment of C1-C2 (atlanto-axial) motion.\textsuperscript{10} While typically associated with upper cervical dysfunction, some have suggested that CGHs can occur in patients with lower cervical dysfunction, particularly after trauma.\textsuperscript{25,26}

Both history of trauma and patient age may be factors in differentiating upper or lower segmental CGHs. Preadolescent (10-13 year old) children with neck pain and headache have dysfunction of the lower cervical spine.\textsuperscript{27} Cervical osteoarthritis, common in many older patients may be associated with headache and cervical muscle dysfunction.\textsuperscript{28,29} In addition, physical impairments such as cervical range of motion and muscular strength can vary between traumatic and atraumatic CGHs.\textsuperscript{30} Clinicians should remember that diagnosis of CGH should be made by carefully examining the etiology of the headaches, not just the symptoms. Above all, successful treatment of CGH begins with a good clinical examination and accurate diagnosis.

**ASSESSMENT**

Because CGHs are a secondary type of headache, it is important to determine the primary causes that exist by performing a thorough musculoskeletal assessment, particularly of the cervical spine. Dr. Vladimir Janda noted specific patterns of muscle imbalance in patients with cervical dysfunction, including those with cervicogenic headaches.\textsuperscript{31} These patterns of muscle tightness and weakness, known as “Upper Crossed Syndrome” (Figure 1) were further described in several published studies on CGH.\textsuperscript{3,32-37} In addition, several published case studies\textsuperscript{38-40} describe CGH patients with presentations consistent with the Upper Crossed Syndrome.

**Postural Assessment**

Forward head posture is thought to increase stress on the upper cervical segments. Watson and Trott\textsuperscript{36} first noted that forward head posture was more common in CGH patients than other patients, which was also associated with weakness and decreased endurance of the deep neck flexors. More recently, however, Zito and colleagues\textsuperscript{37} found no significant differences in the prevalence of forward head posture in CGH or migraine patients compared to control subjects.

![Janda’s Upper Crossed Syndrome](https://www.humankinetics.com)
Active Range of Motion
Clinicians often measure active cervical ROM in patients with head and neck pain; however, author's results conflict on its validity in CGH. Some authors have reported significant decreases in active ROM in those with CGH, while others have found no significant differences in AROM when compared to asymptomatic subjects. These findings also suggest that subclassifying CGHs into traumatic versus atraumatic origin may be of value, since headache and neck ROM are inversely related in patients who have sustained a whiplash injury.

Muscle Length
Consistent with Janda's Upper Crossed Syndrome, patients with CGH often present with tightness of the sternocleidomastoid, upper trapezius, levator, scalenes, suboccipitals, pectoralis minor, and pectoralis major. These muscle length tests are described elsewhere. Treleaven and colleagues used a tightness scale to rate muscle length using normal, slight, moderate, and severe tightness.

Muscle Strength and Activation
Janda also noted that patients with cervical dysfunction often have weakness of their deep neck flexors. Several researchers have confirmed decreased strength and endurance of the deep neck flexors in CGH patients. Janda recommended the active neck flexion movement pattern test to identify patients with weakness of the deep neck flexors. With the patient supine and knees bent, he or she is asked to lift the head and look at their toes (Figure 2). Normal movement produces a smooth reversal of the normal cervical lordosis, keeping the chin tucked. Weakness of the deep neck flexors is compensated by tightness of the SCM, producing an early protraction of the chin directly upward at the beginning of the motion.

Jull and colleagues used the craniocervical flexion (CCF) test to demonstrate significant deep neck flexor weakness in CGH patients. The CCF test provides a reliable measure of deep neck flexor performance. During the CCF test (Figure 3), an inflatable cuff with a pressure sensor is inflated to 20 mm Hg and placed under the patient's neck while lying in supine. The patient performs gentle nodding motions of craniocervical flexion while maintaining the target pressure. The pressure is increased by 2 mm Hg over 5 incremental levels with progressive increases in craniocervical flexion range of motion until the patient is able to perform craniocervical flexion while maintaining 30 mm Hg. Other researchers have used electromyography (EMG) to examine neuromuscular function in CGH patients and have found that they exhibit abnormally high activation of the SCM and upper trapezius during muscular strength testing, as well as decreased deep neck flexor activation.

Manual Assessment
Palpable joint dysfunction of the upper cervical spine discriminates between CGH and other headaches as

Figure 2a and 2b. Janda's Cervical Flexion text (a. Normal, b. Abnormal movement patterns)
well as control patients. Manual assessment of the upper cervical segmental mobility and pain has good reliability, with positive findings (pain produced with passive mobilization) in 63% of CGH patients and a sensitivity of 80%. All manual assessments of cervical patients should begin with a vertebrobasilar artery (VBA) test to rule out arterial insufficiency. Patients who sustain a VBA stroke often have preliminary symptoms of headache and neck pain, but the risk of VBA stroke after spinal manipulation remains minimal, roughly at the same level of risk as visiting a primary care physician.

**Cervical Flexion-Rotation Test**

During the Cervical Flexion Rotation Test (CFR), the patient is supine and the examiner flexes the cervical spine fully in order to block rotational movement below the atlanto-axial articulation. The examiner then passively rotates the head left and right, determining range of motion (ROM) and end-feel. A firm end-feel with limited ROM presumes limited rotation of the atlas on the axis.

Using the CFR test, patients with CGH average 25-28° of A-A rotation to the side of the headache as compared to an average rotation of 44° in asymptomatic patients. Patients with migraine and other types of headaches may also be limited in CFR motion, averaging 42° and 35° respectively in either direction. Some authors have suggested that the degree of ROM restriction is not related to the severity of CGH symptoms, while others have found as little as 6° restriction can be related to headache intensity. The CFR has been shown to have an overall diagnostic accuracy of 85-91%. It is important to remember that limited rotation to one side may be due to tightness of the contralateral suboccipital muscles, and not necessarily impaired C1-2 rotation, thus a careful examination of soft tissue restriction is also important.

**Breathing Pattern**

Diaphragmatic breathing allows the lungs to fill on inspiration by increasing chest volume. In patients with diaphragm dysfunction, the accessory respiratory muscles (scalenes and SCM) lift the rib cage to facilitate lung filling during inspiration. These secondary muscles are often tight and hyperactive in patients with chronic neck pain due to deep neck flexor weakness. In faulty respiration patterns, these tight muscles are readily activated and continue to facilitate the patterns of muscle imbalance with each breath.
**Soft Tissue Assessment**

Cervicogenic headache patients have a high probability of having myofascial trigger point pain, particularly from overactivity of the SCM, upper trapezius, and temporalis. Myofascial trigger points of the SCM have a similar referred pain pattern to that seen in CGH (posterior to frontal). In fact, Jaeger found that 12 out of 12 CGH patients had at least 3 myofascial trigger points on their symptomatic side which reproduced their headaches over 50% of the time.

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**INTERVENTION**

Medical management usually begins with pharmacologic intervention; however, CGH patients frequently do not respond to medications. More invasive procedures have been suggested in the literature such as occipital nerve blocks, anesthetic and steroid blockades, and treatment with pulsed radiofrequency energy. Because of the risks associated with these procedures, and the lack of well-controlled outcomes studies, more conservative interventions are typically prescribed.

As stated previously, an accurate diagnosis is the key to successful treatment. A comprehensive musculoskeletal examination will identify specific impairments upon which the sports physical therapist can focus in order to relieve CGH symptoms. Impairments associated with concomitant conditions such as TMJ disorder should be addressed which will improve outcomes. Several factors have been associated with better outcomes in CGH patients: older patients, provocation or relief of headache with movement, and gainful employment. A multi-modal approach including modalities, manual therapy, and therapeutic exercise is recommended to address individual impairments in CGH patients.

**Modalities**

Modalities are frequently used by sports physical therapists to help reduce pain and facilitate healing. Few studies have investigated the effectiveness of modalities in CGH patients. There is some support for TENS and cryotherapy in combination with other therapies.

Low-level laser therapy (LLLT) is becoming an increasingly popular modality for treatment of a variety of musculoskeletal conditions. Unfortunately, there are no known clinical studies on the use of LLLT in CGH patients. In a recent systematic review, Chow et al concluded that LLLT reduces pain immediately after treatment in acute mechanical neck pain and up to 22 weeks after treatment in patients with chronic neck pain, while Leaver et al. suggested LLLT is more effective in the intermediate and long-term than short term. Furthermore, laser acupuncture was shown more effective than placebo in treating chronic tension-type headaches.

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**Manual Therapy**

Because CGH is related to cervical joint dysfunction, most studies on CGH treatment have focused on joint mobilization and manipulation. Several studies of varied research designs have shown that spinal manipulative therapy (SMT) is effective for CGH, particularly those focused on treatment of the upper cervical segments. Systematic reviews of randomized control trials using manual therapy in CGH patients suggest better outcomes compared to no treatment, although there is a need for more high quality clinical studies. Both mobilization and manipulation are effective for treatment of patients with cervical pain, although manipulation appears superior to mobilization in the short term. In addition, patients with neck pain with or without headache have more short-term relief when manual therapy is combined with exercise as compared to exercise alone.

**Muscle Stretching**

Patients with CGHs often have tightness of the SCM, upper trapezius, levator, scalenes, suboccipitals, pectoralis minor, and pectoralis major. The post-isometric relaxation (PIR) technique is useful in helping reduce tightness and trigger point pain. PIR is performed by first passively lengthening the muscle, then having the patient contract (10-20% of maximum) against resistance for 5 seconds passively before exhaling and relaxing the muscle and repeated. The clinician then takes up the slack within the muscle and repeats the technique 3 to 5 times.

Gebauer’s Spray and Stretch® can also be used to address muscle tightness and trigger points located both in the cervical and facial musculature. Trigger points often refer pain in the cranial region, creating headache-like symptoms; muscles whose trigger points...
points may present headache like symptoms include the suboccipitals, SCM, and temporalis. In addition, scalene trigger points can refer pain down the arm as is sometimes seen in CGH patients. Simons and colleagues offer an excellent description of the spray and stretch technique in their textbook.

**Instrument-Assisted Soft Tissue Mobilization (IASTM)**

The fascia is an important and often overlooked tissue that often contributes to chronic musculoskeletal pain. Astute therapists realize that fascial contributors to pain must be addressed. Several different fascial layers exist in the cervical spine. Fascial connections exist between the suboccipital muscles and upper cervical dura, which attaches to the cranial fossa and C2 vertebra. Adhesions in these fascial connections may restrict normal movement of muscle between fascial planes. While no studies have examined the efficacy of IASTM in headache or neck patients, clinicians may use techniques such as Graston® Technique or ASTYM® to address soft-tissue restrictions and pain in the upper cervical region, particularly in the suboccipitals, SCM, upper trapezius, and levator. Manual myofascial stretching is a hallmark of soft tissue intervention in patients with cervical pain and dysfunction. While instruments can facilitate soft tissue assessment and mobilization, hands-on myofascial techniques can also be helpful.

**Therapeutic Exercise**

Unfortunately, there are few studies focusing on the effectiveness of therapeutic exercise in patients with CGH. With this lack of specific evidence, and until more is available, clinicians may make clinical decisions on exercise prescription based on research conducted in patients with either chronic neck pain or headaches. As stated previously, clinicians should address individual impairments in CGH patients which may include poor posture, motor control, muscle length, and muscle strength and endurance impairments.

Therapeutic exercise intervention should start by addressing and teaching postural awareness. Patients with cervical pain often exhibit forward head posture and rounded shoulders associated with muscle imbalance. Reinforcing good posture through regular cuing can help reinforce the stretching and strengthening exercises to restore muscle balance. A good ‘proprioceptive posture’ begins from the core, ensuring the patient knows how to activate the transverse abdominus and brace the entire core. In addition, patients should be instructed in proper diaphragmatic breathing to reduce activation of accessory respiratory muscles as suggested in Travel’s textbook.

Cervicogenic headaches are thought to be a dysfunction of the sensorimotor system, rather than a true structural problem. Sensorimotor dysfunction manifests itself in the neuromusculoskeletal system in motor control and movement impairments. Jull and colleagues used a specific exercise, the ‘craniocervical flexion’ (CCF) exercise for activating the deep neck flexors in patients with chronic cervical pain.

![Figure 5. Dynamic Cervical Extension Exercise. The patient performs a ‘hip hinge’, stabilizing the cervical spine against the resistance in 4 directions (Used with permission of The Hygenic corporation).](image)
In their randomized controlled trial of 200 patients with CGH, Jull and colleagues found that 6 weeks of the CCF exercise was as effective as spinal manipulation at reducing headache frequency and intensity, as well as cervical pain up to 1 year.

During the CCF exercise, an inflatable pressure cuff is placed behind the neck as the patient lies supine as described previously for the CCF Test (Recall Figure 3). The cuff is inflated to 20 mm Hg and the patient is instructed to very slowly flex the upper cervical spine with a gentle nodding motion and hold steady for 10 seconds without activating the SCM. The exercise is progressed by increasing the cuff inflation by 10 mm Hg toward a goal of 40 mm Hg. Compared to normal cervical flexion, the CCF has lower activation of the SCM, which may be desirable in patients with muscle imbalance. While this biofeedback using the pressure gauge may be effective, similar exercises can be performed at home using a towel roll. Begin in supine with the exercise and progress to combining with bilateral arm raise. Further progress the patient to a sitting position with their back against a wall while performing the same exercise. Finally, other unsupported postures must be utilized to allow patients to transition to normal, functional movement positions.

Jull and colleagues reported that their CCF exercise was more effective than a strengthening exercise involving resisted neck flexion in patients with chronic neck pain; however, Ask et al found no significant difference between the CCF exercise and a 'dynamic isometric' neck strengthening exercise using elastic bands in whiplash patients. Their strengthening program was based on work by Dr. Jari Ylinen and his colleagues in Finland on women with chronic neck pain. The exercise program has been shown to be effective in reducing chronic neck pain as well as cervicogenic headaches. Ylinen's program includes a high-intensity, 4-direction dynamic isometric exercise of the cervical spine and strengthening and stretching exercises for the upper quarter. The patient stabilizes the neck and performs a 'hip-hinge' over 20-30 degrees against elastic band resistance (Figure 5). The exercise is performed in flexion, extension, and sidebending to both sides.

Figure 6a-b: Craniocervical flexion against elastic band loop. Begin with cervical spine in protraction (a). Maintain hand position while retracting against the tension in the band (b). (Used with permission of The Hygenic Corporation).
Van Ettekoven and Lucas\textsuperscript{92} completed a 6-week randomized controlled trial on patients with tension-type headaches who were assigned to either a passive (massage and manual therapy) or active (massage, manual therapy and exercise) group. The exercise group performed craniocervical flexion exercise (Figure 6) against an elastic resistance band for 6 weeks. The exercise group had significantly reduced frequency, intensity and duration up to 6 months after the program. Although this study was not performed on patients with CGH, the positive results lend support for utilizing this exercise in CGH patients.

Exercises to improve upper quarter strength, particularly of the axio-scapulo-humeral musculature, are important.\textsuperscript{93} Most recently, Andersen and colleagues\textsuperscript{94} demonstrated that 2 minutes per day, 5 days per week of a standing lateral raise exercise with elastic tubing significantly reduced neck-shoulder pain and headaches in office workers. Several other clinical intervention studies on chronic neck pain and CGH\textsuperscript{83,94-96} have utilized a variety of upper quarter strengthening exercises including:

- Shoulder abduction
- Shoulder retraction
- Lat pull-down
- Push-up
- Chest press
- Shrug
- Arm curl
- Bent-over row
- Chest flies

Adding upper quarter exercises for patients with cervical dysfunction is important in order to integrate ‘global’ muscles that have connections to the cervical spine through anatomical chains; most notably those connecting the axial and appendicular skeletons.

Finally, because CGHs are thought to be a dysfunction of the sensorimotor system, rather than a true structural problem, sensorimotor training should be included in the rehabilitation program.\textsuperscript{97} Sensorimotor exercises include progressive exercise on unstable surfaces to promote reflexive stabilization and postural stability. Unstable surfaces such as exercise balls or foam pads can be used to add challenge to the cervical spine as well as the whole-body for stabilization exercises (Figure 7). These final stages of the rehabilitation program for CGH patients can be progressed toward functional activities to return the patient or athlete to full participation.

In summary, CGHs are caused by neck dysfunction, typically of the upper cervical spine, although the specific etiology remains unclear. Cervicogenic headaches are associated with musculoskeletal dysfunction and muscle imbalance with characteristic patterns of muscle weakness and tightness. A thorough history and clinical examination will lead to an accurate
diagnosis. As with other musculoskeletal dysfunctions, a multi-modal physical therapy intervention is recommended to address individual impairments including modalities, manual therapy, and therapeutic exercise. It's important for sports physical therapists to make an accurate diagnosis and provide an appropriate intervention to return the athlete with CGHs to sports as soon as possible.

REFERENCES


ABSTRACT

During the initial assessment of the injured athlete, the Sports Physical Therapist (PT) must first be concerned with life-threatening emergencies such as absence of breathing and pulse. The sports PT must also be aware of the possibility of “sudden cardiac death” that could occur in others, including coaches, officials, and fans. If the PT assumes the role of “most medical” person at the contest or event, the responsibility for life saving action falls squarely on their shoulders. Therefore, skills and ongoing certification in cardiopulmonary resuscitation techniques and the use of an automated external defibrillator are a basic necessity. These skills are required as part of the specialty practice of sports PT (BLS Healthcare Provider course or CPR for the Professional Rescuer in addition to completion of the First Responder Course OR credentials as an EMT or ATC), and are mandatory for being qualified to sit for the exam to become a sports certified specialist (SCS) by the American Board of Physical Therapy Specialties (ABPTS).3

Key Words: automated external defibrillator, cardiopulmonary resuscitation and emergency response
INTRODUCTION
During the initial assessment of the injured athlete, the Sports Physical Therapist (PT) must first be concerned with life-threatening emergencies such as absence of breathing and pulse. If the athlete is conscious and talking, the athlete has a pulse and is breathing. However, should the athlete be found unconscious on the field or court, the initial concern of the sports PT should be the immediate threats to the life of the athlete. There are numerous reports of athletes suffering “sudden cardiac death” while participating in both competition and practice situations.1,2 The sports PT must also be aware of the possibility of “sudden cardiac death” that could occur in others, including coaches, officials, and fans. If the PT assumes the role of “most medical” person at the contest or event, the responsibility for life saving action falls squarely on their shoulders. Therefore, skills and ongoing certification in cardio-pulmonary resuscitation techniques and the use of an automated external defibrillator are a basic necessity. These skills are required as part of the specialty practice of sports PT (BLS Healthcare Provider course or CPR for the Professional Rescuer in addition to completion of the First Responder Course OR credentials as an EMT or ATC), and are mandatory for being qualified to sit for the exam to become a sports certified specialist (SCS) by the American Board of Physical Therapy Specialties (ABPTS).3

SIGNS AND SYMPTOMS OF CARDIAC EMERGENCY
The most noticeable symptom of a heart attack is complaint of persistent chest pain or pressure in the chest. These symptoms are often ignored as related to indigestion, muscle spasms, chest cold, or other chest related maladies. However, in athletes who experience cardiac events during participation, these symptoms are typically absent and the first symptom is loss of consciousness for no apparent reason during a game or a practice session. Sudden cardiac emergencies, although uncommon, must be recognized as critical, and the prepared provider must have a plan for management of these situations. The PT must take immediate action in the evaluation of the athlete by determining if a pulse and/or respiration is present. If no respiration is present, the pulse will soon fail.

CARDIOPULMONARY ASSESSMENT AND RESUSCITATION
All PT’s should be competent in performance of cardiopulmonary resuscitation (CPR) and should maintain CPR certification. The direction “Look, Listen, and Feel” for air moving in and out of the lungs of the athlete is the standard for determining respiratory effort. Should no respiratory effort be noted, the airway of the athlete must be opened by extension of the cervical spine and tilting the head in a posterior direction. If there is any concern about an injury to the cervical spine, the chin lift-jaw thrust maneuver should be used. If no movement of air is detected, rescue breathing must be initiated using mouth to mouth technique, or through the use of a barrier such as a resuscitation mask in order to provide the flow of oxygen into the lungs of the victim. Two rescue breaths are the standard, making certain the chest rises with each breath. The PT should then check the carotid pulse to determine if a pulse is present.

Should no pulse be detected, immediate initiation of cardio-pulmonary resuscitation (CPR) is initiated after calling 911 or sending someone to make the call to 911. The correct hand position on the chest is found by locating the xiphoid process or the tip of the sternum, place your middle finger on the notch and place your index finger next to your middle finger. Next, place the heel of your hand next to your middle finger. Once your hand is in position, place your other hand on top of the first hand and interlock you fingers using the top hand to keep the fingers of the lower hand off the chest. Position yourself directly over the chest of the victim.

Figure 1. Proper hand placement for CPR, note proper elbow position as well.
with your elbows locked and the weight of your trunk over your elbows. (Figure 1) Begin 30 compressions at the rate of 100 compressions per minute. For an adult, compress the sternum at least 2 inches. For a child, the compressions should be to a depth of about 2 inches, and for an infant the depth of compression should be about 1 1/2 inches. Continue at the rate of 30 compressions to 2 breaths for approximately 2 minutes, then recheck breathing and pulse. All sports PT should have specialized training in one person, two person and three person CPR as well as airway insertion, use of a bag-valve-mask resuscitator, and oxygen administration. In athletic settings, this is continued until the arrival of a medical response team.

THE AUTOMATED EXTERNAL DEFIBRILLATOR

AEDs are portable electronic devices that have the capability of analyzing heart rhythm and delivering a shock to the heart when indicated. (Figure 2) The AED can greatly increase the likelihood of survival if administered soon enough, in fact reducing the time to defibrillation after an event improves survival in out of hospital cardiac arrest situations. Most experts recommend a three (3) minute “drop to shock” application to increase the likelihood of survival. There are a number of AED manufacturers today, however, most AED's have common features such as visual displays, auditory prompts, and lighted buttons with instructions as to when to deliver a shock if indicated. The AED will determine if there is a "shockable rhythm" in the heart that will respond to defibrillation. These units give specific demands related to the use of the AED as well as reminders to call 911, open the airway, check for pulse, beginning CPR, etc. Most AED’s come with specified pads to be used with the unit. (Figure 3) AED manufacturers have simplified the units to make safe and efficient operation very simple. Special training is required for the use of the AED to assure safe and effective application of the shock. AED training is obtainable at CPR/AED courses or as a part of the Emergency Responder preparation course.

All PT's should also be trained in the use of an Automated External Defibrillator (AED). In the clinic area, an AED should be available to all clinicians and staff members, who should also be educated in the proper use of the AED. Recall the three (3) minute “drop to shock” rule in the event of a cardiac emergency. This applies not only on the athletic field or court, but also in outpatient clinical settings. Should a patient in the clinic show signs of cardiac distress, a call to 911 is indicated and immediate application of the AED should be carried out, even if the victim is conscious and alert. Do not wait until the victim loses consciousness as a result of a cardiac emergency in order to apply the AED. Remember, the AED functions as a diagnostic tool; if a normal sinus rhythm is present, the AED will not allow a shock to be delivered. Should a shockable rhythm be noted by the AED, the AED can be promptly utilized to attempt to restore normal sinus rhythm.

The competent use of an AED is an essential part of the practice of sports PT. (Figures 4, 5) The presence of the AED is indicated on the sidelines or at court side of

Figure 2. Automated External Defibrillator (Zoll AEDPLUS, Dixie Medical Inc., Franklin, TN).

Figure 3. AED pads out of the box (Zoll AEDPLUS pads, Dixie Medical Inc., Franklin, TN), note scissors and razor for use prior to application.
athletic events. According to the consensus task force authors, “in any collapsed and unresponsive athlete, SCA [sudden cardiac arrest] should be suspected and an AED applied as soon as possible for rhythm analysis and defibrillation if indicated”5, p. 56. The likelihood of the use of the AED on athletes is minimal compared to the potential use of the AED on game officials, coaches, and those individuals in attendance at the athletic event. Many times, the sports PT is the “most medical” person present and would be looked upon as the individual to respond to a cardiac emergency. The presence of the AED makes response more effective and efficient. In fact, the authors of the consensus statement published in 2007 stated that prompt recognition of emergent situations, access to an AED for early defibrillation, coordination of onsite responders and AED training programs, and presence of a trained rescuer all increase the possibility of successful management of a sudden cardiac incident.6

CONCLUSIONS
The practice of sports PT requires quick decision-making in emergent conditions. This includes competency in providing CPR and in the use of an AED when indicated. Whether in a clinic or sideline/court setting, the sports PT must have a plan for managing any sudden cardiac event or other emergent condition that may occur, in athletes and/or patients, as well as spectators and others present at contests. Table one provides a summary of the progression of a typical emergency response. (Table 1).

Table 1. Basic AED Protocol.

1. Begin with standard CPR protocol including call to 911
2. Open unit and turn on power (unless unit powers itself when opened)
3. Connect cables
4. Expose chest and clean as necessary including hair removal
5. Peel off backing of electrodes
6. Apply pads as directed
7. Follow prompts as directed by AED
8. Stop CPR when indicated, in order to allow AED to analyze the status of the victim
9. Prompt for shock- make sure no one is touching the victim
10. Deliver shock
11. Recheck pulse
12. Begin CPR for 1 minute if indicated
13. Re-analyze and deliver shock if indicated, by the AED by following prompts.

REFERENCES
ABSTRACT

Study Design: Correlation study

Objectives: To objectively evaluate the relationship between core stability and athletic performance measures in male and female collegiate athletes.

Background: The relationship between core stability and athletic performance has yet to be quantified in the available literature. The current literature does not demonstrate whether or not core strength relates to functional performance. Questions remain regarding the most important components of core stability, the role of sport specificity, and the measurement of core stability in relation to athletic performance.

Methods: A sample of 35 volunteer student athletes from Asbury College (NAIA Division II) provided informed consent. Participants performed a series of five tests: double leg lowering (core stability test), the forty yard dash, the T-test, vertical jump, and a medicine ball throw. Participants performed three trials of each test in a randomized order.

Results: Correlations between the core stability test and each of the other four performance tests were determined using a General Linear Model. Medicine ball throw negatively correlated to the core stability test ($r = -0.389$, $p = 0.023$). Participants that performed better on the core stability test had a stronger negative correlation to the medicine ball throw ($r = -0.527$). Gender was the most strongly correlated variable to core strength, males with a mean measurement of double leg lowering of 47.43 degrees compared to females having a mean of 54.75 degrees.

Conclusions: There appears to be a link between a core stability test and athletic performance tests; however, more research is needed to provide a definitive answer on the nature of this relationship. Ideally, specific performance tests will be able to better define and to examine relationships to core stability. Future studies should also seek to determine if there are specific sub-categories of core stability which are most important to allow for optimal training and performance for individual sports.

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INTRODUCTION
Core training has become the norm in many athletic training programs throughout the United States during the past decade. Equipment such as the therapy ball, BOSU™ ball (Fitness Quest, Canton, Ohio), and the abdominal roller have been described as quick and easy fitness solutions for our exercise deprived society. The mantra of “core training” makes athletes believe that enhanced core stability will improve their performance on the field or court. Although the media portrays these ideas as truth, the scientific community remains uncertain as to the relationship between core stability and athletic performance. This relationship may prove challenging to define because functional and core demands are typically sport or position specific and many questions, such as which element of core stability is most essential to performance, remain unanswered. The purpose of this pilot study is to analyze the relationship between a test of core stability and athletic performance measures.

The current literature offers a variety of suggestions for defining core stability, but remains unclear on a precise conclusion. According to Tse et al., “The core musculature includes muscles of the trunk and pelvis that are responsible for maintaining the stability of the spine and pelvis and are critical for the transfer of energy from larger torso to smaller extremities during many sports activities.” Therefore, it is theoretically believed that if the extremities are strong and the core is weak the decrease in muscular summation through the core will result in less force production and inefficient movement patterns. Kibler et al. defines core stability as “the ability to control the position and motion of the trunk over the pelvis to allow optimum production, transfer, and control of force and motion to the terminal segment in integrated athletic activities.” Panjabi stated that core stability is achieved by the integration of the active spinal stabilizers (muscles), passive stabilizers (spinal column), and neural control which act together to control intervertebral joint range of motion in order to allow for the performance of activities of daily living. Thus, the definition of core stability may depend strongly on the context in which it is applied. Hibbs et al. propose that elite level athletes require much higher levels of core stability for sport performance than during activities of daily living, therefore they must have appropriate rehabilitation to enhance return to function. These definitions suggest that core stability in athletics involves dynamically controlling and transferring large forces from the upper and lower extremities through the core in order to maximize performance and promote efficient biomechanics.

Many different models of the core anatomy have been proposed in the literature that attempt to explain the complex interaction between the muscular and neural elements. These models often differ depending on the context in which they were developed. Some researchers have described the core as a double walled cylinder with the diaphragm as the roof, abdominals as the front, paraspinals and gluteals as the back, and the pelvic floor and hip musculature as the bottom. Researchers with a specific interest in sports suggest that the core includes all the musculature between the sternum and knees, with a specific focus on the low back, hips, and abdominals. It has also been suggested that the core should include the muscles of the shoulder and pelvis because they are critical in the transfer of forces across the body.

Bergmark explained the function of the core musculature by dividing the trunk muscles into local and global categories. Local muscles are defined as those attaching to the lumbar vertebral and influencing inter-segmental motion, while global muscles attach to the hips and pelvis and promote mobility and proper orientation of the spine. Bergmark stated that maintaining balance in these muscles is important because if the local muscles are not functioning properly, movements become inefficient due to compensation of the global muscles thus altering stability.

Nichols expanded on Bergmark’s work by dividing the core musculature into muscles that operate by length dependent and force dependent activation patterns. He elaborated that the muscles operating on length dependent patterns are small, short muscles with small lever arms that typically span one joint. The force dependent muscles cover multiple spinal segments, produce higher levels of force, and coordinate multiple joints. Accordingly, it is the combination of both muscle activation patterns that allows for control of the multi-segmented spine and the neutralizing of forces.
In order to completely understand the concept of core stability, it is essential to be aware of the role that each muscle plays in the overall scheme of coordinated movement. The abdominal muscles, consisting of the transversus abdominis, rectus abdominis, and internal and external obliques, are primarily involved in controlling the position of the spine and pelvis. The transversus abdominis increases intra-abdominal pressure and tensions the thoracolumbar fascia while the abdominals collectively contract to create a rigid cylinder to stabilize the spine.\textsuperscript{10,11} It is the thoracolumbar fascia that connects the upper and lower extremities in order to integrate the superior/inferior and right/left parts of the kinetic chain. The thoracolumbar fascia is also connected to the internal obliques and transversus abdominis and functions to provide further cylindrical stabilization to the spine.\textsuperscript{12} The diaphragm also has been shown to assist with spinal stability by contracting prior to limb movement and independent of respiration.\textsuperscript{13}

The hip and pelvic floor musculature serves as the base of support for the core. According to Hodges\textsuperscript{14}, synergistic activation patterns exist in pelvic and trunk controlling musculature. The hip musculature, with its large cross-sectional area, is involved with stabilization of the trunk as well as force and power generation during lower extremity movements in sports activities. The gluteal muscles stabilize the trunk over a planted leg in order to supply power for forward leg motions in movements such as throwing and running.\textsuperscript{15,16} For efficient and skillful movement to occur, the collective musculature of the core must be activated in precise patterns to both generate and absorb force while stabilizing the trunk.

To maintain stability of the core, the body must integrate sensory, motor-processing, and biomechanical strategies coupled with learned responses and the ability to anticipate change.\textsuperscript{17} Thus, the body must control the trunk in response to internal and external perturbations, which include forces generated by the distal extremities as well as expected/unexpected challenges to stability.\textsuperscript{18} Anticipatory postural adjustments of the core are determined by pre-programmed muscle activations.\textsuperscript{2} Ebenbichler et al\textsuperscript{13} demonstrated this concept in showing that other muscles contract before the limb agonist when stability is challenged due to limb movement. These postural adjustments allow the body to increase proximal stability and allow distal mobility. Additional studies which have analyzed the response of the superficial muscles in response to external perturbations have revealed a direction-specific activation pattern in order to maintain proper orientation of the spine.\textsuperscript{19,20} Some studies on the function of the transversus abdominis have revealed an activation pattern that is independent of the direction of externally applied force while more current studies have reported that feed forward activity of the muscle is not bilaterally symmetrical and is specific to the direction of arm movement.\textsuperscript{11,21}

The importance of the neuromuscular system, as it pertains to the core, has been clarified through research specifically addressing muscle activation patterns during sports activities. It has been demonstrated that, in response to rapid arm movements, muscle activation patterns begin in the lower extremity and proceed upwards through the trunk and to the arm.\textsuperscript{22} This pattern of force development from the ground through the core to the extremity has been shown in tennis\textsuperscript{16}, baseball\textsuperscript{23}, and kicking activities.\textsuperscript{15} Cook\textsuperscript{24} described the concept of alternating patterns of joint stability and mobility throughout the body that serves to enable functional activities and that loss of stability at one joint requires provision of stability at the adjoining segments. Researchers have demonstrated a similar analysis in pitching as there is a consistent pattern of muscle activation that begins with the contra-lateral external oblique and proceeds to the arm.\textsuperscript{23} The importance of core stability is further evidenced by findings that suggest the trunk and peri-scapular muscles are responsible for nearly 85\% of the muscle activation required to decelerate the forward moving arm during throwing.\textsuperscript{25} These findings provide a basis for further research to evaluate the specific role of core stability in performance, injury, and rehabilitation.

The relationship between core stability and injury prevention is also relevant. A study by Zazulak et al\textsuperscript{26} evaluated trunk displacement and stiffness in response to movement, as well as the ability to determine spatial position of the trunk. Results of the study indicated that factors related to core stability predicted knee injury with high levels of sensitivity and moderate specificity in female but not male athletes. An
et al\(^1\) analyzed the effectiveness of an 8 week core endurance exercise protocol on college aged male rowers. At the conclusion of the study, the authors reported that although their program did improve core endurance, but did not improve functional performance in tests such as the vertical jump, broad jump, shuttle run, and 40 m sprint. This led the researchers to state that core strength and power may be more influential in functional performance. Stanton et al\(^3\) studied the effects of short term therapy ball training on core stability and running economy. It was found that the therapy ball training resulted in improvement of what they defined as core stability, but had no effect on physical performance measures. Scibek et al\(^3\) noted similar results in a study that investigated the effects therapy ball training on swimming performance. It was noted that therapy ball training improved core stability measurements, but did not transfer to improved swim performance. Sato and Mokha\(^3\) studied the effects of a 6 week core stabilization training program on ground reaction forces, stability of the lower extremity, and overall running performance in recreational and competitive runners. Their results indicated a significant improvement in 5000 meter running times with no changes in ground reaction forces or leg stability. Multiple interventions related to the design of the study, precludes the conclusion that core stability training specifically improved running performance. It can be summarized from the studies discussed above that although core training has been shown to improve core stability; the results have not translated into performance enhancement.

The aim of this research was to investigate the relationship between core stability, measured by the double leg lowering test (DLL), and athletic performance tests in college athletes. Currently, the literature does not identify a single test or battery of tests which are considered to the most effective for evaluating core stability. However, based on the available evidence the authors have concluded that the DLL test is an appropriate way to measure core stability as it pertains to athletic function. The DLL test has been shown to require significant levels of muscle activation\(^3\) and required a high level of intrinsic trunk stabilization due to the long lever arm of the legs and a narrow base of support for the trunk and upper extremities. Lanning et al\(^4\) gave further support for...
seek treatment in the past 60 days. All participants performed 10–15 minutes of warm-up activities before participating in any of the athletic testing stations. The athletes reported to the testing site in groups related to their team membership and completed the test sequence as a team. Activities were completed by 34 of the 35 subjects (97%). One male soccer player dropped out after experiencing foot pain, portions of his data were recorded and used for analyses.

The subjects were given a scoring sheet before testing in order to allow the researchers to record their performance at each athletic testing station. The scoring sheets had the starting position and rotation sequence for the athletic testing sequence in the upper left corner. The sheets had 1 of the 5 possible sequences and were distributed randomly to the subjects as they came in the door. The five testing stations included abdominal leg lowering test, vertical jump, 40-yard dash, T-test, and a medicine ball throw. The vertical jump, 40-yard dash, T-test, and medicine ball throw are not direct measures of sport performance, but they do measure factors or components of many sports. The factors of power, speed, and agility are three components in most sporting events. During the current study, the examiner at each station explained the testing procedure and the proper technique to perform the test. Following instruction subjects were given a practice trial at each testing station in order to allow the subject to acclimate to and understand how to perform the test and allow for the best performance possible. The subjects were instructed not to perform at maximum exertion during the practice trial. The subjects were given the opportunity to ask questions of the examiner at the station for further explanation about the test. The examiner gave no other feedback except to correct any improper technique as outlined by the researchers in the instruction. The subject was given a 4 minute rest period following the practice trial before the first recorded performance. During the recorded performance subjects were not given encouragement or feedback from the examiner except to correct any improper technique as outlined by the researchers in the instruction. Once the subject completed the performance at the first testing station he/she rotated to the next testing station on his/her list. Each subject was given a minimum of a 4 minute break between each testing station in order to allow

The objective of this study was to critically evaluate the relationship between a core stability test and athletic performance measures. Several studies have examined the impact of core muscle training on performance outcomes with minimal success and few conclusions. It appears that the focus of research in this area may need to first be directed to research to determine whether tests of core stability are related to athletic performance measures. The gathered data was analyzed to elucidate this relationship as it pertains to male and female athletes in a variety of sports. It is possible that performance in specific sports is highly correlated to specific measures of athletic performance, while other sports demonstrate no relationship. Therefore, to achieve excellent performance in certain sports may require varied levels of core stability. Findings such as these would greatly impact the sports performance and rehabilitation literature because it would serve as the basis for sport specific exercise prescription and help with identifying appropriate training for higher level athletes. If this relationship can be described using objective and valid measures, further research can focus on sport specific core stabilization training programs based on the specific functional demands of varied sports or activities in order to enhance rehabilitation efforts.

MATERIALS AND METHODS

Thirty-five volunteer subjects were tested at Asbury College Luce Physical Activities Center. The subjects were all student athletes from Asbury College (NAIA Division II). The athletic teams represented in the current study population included: men’s basketball (2), women’s basketball (8), men’s soccer (7), women’s tennis (1), women’s volleyball (7), and men’s/ women’s swimming (4 female/6 male). Average age was 19.25 years with a range of 18–22. Subjects were excluded if they had experienced a musculoskeletal and/or abdominal injury which required them to

the use of the DLL test, which focuses on core stability during lower extremity motion, noting that athletic skills require coordinated and synchronized contractions of the abdominals and lower extremity musculature simultaneously. Krause et al35 reported that in healthy subjects the DLL test has excellent intra-tester reliability, thus providing further evidence for the use of the test in the current study.

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sequence, the test was terminated. The participants were monitored during the test to ensure all sequences were completed successfully without knocking over cones. The athletes were not allowed to cross their feet with the side shuffle. If a sequence was performed incorrectly, the test was terminated and the participant repeated the test after a 4 minute break. Timing was determined using a digital stopwatch. If the procedure was performed correctly the examiner recorded the score to the nearest hundredth of a second.

The 40 yard dash is a measure of power and speed. The athlete needs power to initiate movement and accelerate quickly to top speed. The athlete needs speed in order to cover the course as quickly as possible. The 40-yard dash consisted of a 40 yard linear course marked by cones. The subjects were instructed to run his/her hardest from point A to point B. Each subject was given one practice trial if he/she desired. The subject began the test at his or her discretion and timing began with the first observed movement coming out of a sprinting starting position. Once the participant crossed the finish line the test was terminated. If the subject tripped or stumbled at any point during the 40 yards, the test was terminated and the subject took a 4 minute break before repeating the test station. Timing was recorded via a digital stopwatch. If the procedure was performed correctly the examiner recorded the score to the nearest hundredth of a second.

The medicine ball throw is a measure of power. Many athletes need explosive power in his/her upper extremities in order to throw the ball or propel an object. The examiner used a marked line on the floor as the starting reference for this testing station. A padded mat was placed on the floor and the front of the mat was aligned with a reference line. Before the testing procedures began the examiner taped a measuring tape on the ground out to 50 feet. The examiner instructed the subject to tall kneel (90 degrees of knee flexion and neutral trunk position) on the front of the mat with the medicine ball held at his/her chest level against the chest wall. The male subjects used a 6.6 pound medicine ball and the female subjects used a 4.2 pound medicine ball as recommended by Stockbrugger. From this position the subject was instructed to throw the medicine ball,
The subject was instructed not to “rock back” or “pump” the ball before initiating the throw to minimize momentum and muscle substitution. The subject was allowed to come forward after the throw but was not allowed to catch himself/herself with his/her hands. If the subject performed the procedure improperly no score was given, the technique was corrected, and he/she took a 4 minute break before repeating the testing station. The subject was given a practice trial before initiating the recorded performance. The subject was instructed to throw the ball as far as they could next to the tape measure. The examiner marked the first contact site with the floor and used the tape measure to determine the distance. If the procedure was performed correctly, the examiner recorded the score to the nearest inch.

The vertical jump is also an assessment of power. Many athletes need explosive lower extremity power in order to get off the ground and reach a maximum jump height. The examiner used a Vertec (Vertical Jump Tester – Sports Imports, Columbus, Ohio) to measure the vertical jump of the subjects. The examiner first measured each subject’s reach with the Vertec Vertical Jump Tester and adjusted the height of the device as necessary. The examiner instructed the subjects to jump off both feet with no step into the movement. The subjects were allowed to squat, but no movement of the feet was allowed prior to the jump itself. The arms were allowed to swing as desired by the athlete. The subject was instructed to jump as high as he/she possibly could and deflect as many of the measurement bars on the device as possible. After instructions subjects were given one practice trial to perform the technique. If the subject performed the procedure improperly no score was given, the technique was corrected, and the subject was given a 4 minute rest before retesting. If the procedure was performed correctly the examiner recorded the score to the nearest one half-inch.

The final testing station was the double leg lowering station measuring abdominal strength, which served as the test of core stability. The examiner positioned a flat table in the corner of the room. A large goniometer was drawn on a poster board and taped on the wall next to the table. The subject was positioned on the table in supine with their greater trochanter approximating the axis point of the goniometer. The examiner first taught the subject how to move the pelvis into a posterior pelvic tilt. In this position the low back is flattened against the bed. The examiner did not initiate testing until the subject could perform a posterior pelvic tilt adequately. The examiner instructed the patient to keep his/her back flat against the bed and maintain the posterior tilt of the pelvis as he/she lowered their legs from 90 degrees of hip flexion. The subject was given one practice trial without the stabilizer in place. Following the practice trial the examiner placed a Stabilizer (Chattanooga Corporation, Hixson, Tennessee) underneath the subject’s low back. The Stabilizer in this study was a small blood pressure cuff like device. The bladder was filled with air using a hand pump and there was a dial to read the amount of pressure in the bladder. The patient was instructed to perform a posterior pelvic tilt with the stabilizer under his/her low back. The examiner pumped the stabilizer bladder to 40 pounds of pressure. The subject was instructed and verbally cued to maintain the 40 pounds of pressure throughout the test. The examiner passively lifted the subject’s legs to 90 degrees of hip flexion with bilateral knee extension. The subject actively slowly lowered his/her legs while maintaining a posterior pelvic tilt and the 40 pounds of pressure in the bladder. If the subject was unable to maintain the posterior pelvic tilt, his/her low back came off the table and the pressure would drop in the bladder. When the examiner saw the pressure drop below 40 pounds of pressure (and was unable to regain pressure when urged) he stopped the movement by putting his arms under the patient’s legs. The examiner would measure the angle of the thighs using the wall goniometer as described by Lanning et al. The score was recorded to the nearest degree. If the subject performed the technique incorrectly no score was recorded and the subject repeated the test following a 4 minute rest break.

**STATISTICAL ANALYSIS**

Descriptive statistics were used along with correlation tests in order to determine whether relationships existed between core stability (double leg lowering) and performance on the performance tests (T-Test, 40-yard dash, Vertical Jump, Medicine Ball throw). These values were examined between males and
females separately, athletes of each sport, and the top and bottom performers on the core strength test. The best score that each participant obtained on each of the performance tests was used for correlation analysis with the best score that the participant achieved in the double leg lowering test, using the Pearson Correlation Coefficient. The population was halved using the median score for core stability. The same correlations as above were taken to determine if there was a difference in performance for those with greater core stability. To determine whether statistically significant relationships existed, the p value was determined a priori at p < .05.

ANOVA was used to determine which variables had the greatest influence on the results of each test. Variables, both continuous and discrete, included: age, gender, sport, and the order of testing. Data were analyzed using SPSS software.

RESULTS

Descriptive results for males and females on all performance tests are presented in Tables 1 and 2. The mean degree achieved during the double leg lowering test for females was 54.75 degrees, and 47.43 degrees for males. The lower mean value in this test represents a better score. Recall that this test was selected as a measurement of core strength. Correlational data results showed weak, non-significant correlations between abdominal strength and the T-test (r=0.052), forty-yard dash (r=0.138), and the vertical jump (r=-0.172). A negative correlation was discovered between abdominal strength and the medicine ball throw (r=0.389), however, this correlation may only be considered a weak or low correlation (0.2–0.4 range seen) as most general statistical descriptors of relationship require greater than 0.5 to begin the moderate to strong rankings. The medicine ball throw was the only significant relationship to core strength with a p-value of 0.023. Results can be seen in Table 3.

When the results were divided into male and female categories, the medicine ball throw was still the test that was most strongly correlated to core strength. Male and female data were found to have statistically significant weak correlations (0.2–0.4). See Tables 2 and 3 for data.

To determine if there was a difference in correlation between test values in those who had higher core strength scores and those who had lower core strength scores, the data were halved. The median core strength score was used to divide the participants. Both top and bottom performers showed the strongest and most significant correlation between the medicine ball throw and core strength. The top performers showed a much stronger correlation and significance than the bottom performers. No correlations for the bottom performers were found to be statistically significant. See Tables 4 and 5. Although a General Linear Model through ANOVA was applied (Table 6), a strong relationship to individual variables was not identified.

| Table 1. Correlation between leg lowering and performance tests, all participants (n=35) |
|------------------------------------------|-----------------|-----------------|
| Performance Test (Best Score) | Pearson Correlation (r) | p Values |
| T-Test | 0.052 | 0.768 |
| Forty Yard Dash | 0.138 | 0.438 |
| Vertical Jump | -0.172 | 0.331 |
| Medicine Ball Throw | -0.389 | 0.023* |
| *Statistically significant |

| Table 2. Correlation between leg lowering and performance tests, males only (n=15) |
|------------------------------------------|-----------------|-----------------|
| Performance Test (Best Score) | Pearson Correlation (r) | p Values |
| T-Test | -0.148 | 0.614 |
| Forty Yard Dash | -0.148 | 0.833 |
| Vertical Jump | -0.179 | 0.540 |
| Medicine Ball Throw | -0.322 | 0.026* |
| *Statistically significant |

| Table 3. Correlation between leg lowering and performance tests, females only (n=20) |
|------------------------------------------|-----------------|-----------------|
| Event (Best Score) | Pearson Correlation (r) | p Values |
| T-Test | -0.144 | 0.544 |
| Forty Yard Dash | -0.174 | 0.463 |
| Vertical Jump | 0.217 | 0.358 |
| Medicine Ball Throw | -0.268 | 0.025* |
| *Statistically significant |
DISCUSSION
In theory, it is accepted that core stability and athletic performance are interrelated; however, the current literature does not support this relationship. The purpose of this study was to examine the relationship between a core stability test and tests of performance using the double-leg lowering test as a measure of core strength/stability in male and female collegiate athletes in a variety of sports. The strongest correlation between DLL and functional measures was found with the medicine ball throw, which is a test of muscular power. When the double-leg lowering scores were halved to separate into top and bottom performers, a significant relationship was discovered between the top half of performers and the medicine ball throw compared to the bottom performers. Those perceived as better performers did have a stronger relationship to better throwing while poorer performers did not exhibit a pattern – meaning that they did not show a relationship, either positive or negative.

The results of the current study confirm the work of Scibek\textsuperscript{31}, which discovered a correlation between a forward medicine ball throw and core stability after a six week therapy ball training program with swimmers; however, there was no carryover to test performance or any other sports-specific measures. Current study results are also similar to Nesser et al\textsuperscript{28} who discovered at best only a moderate correlation between several sports-specific measures and core stability. One of the tests used was the bench press, which is a similar test to the medicine ball throw because it is a test of upper extremity power and strength. Other sports-specific measures used in the study included a vertical jump, agility shuttle run, and 20- and 40-yard sprints. The purpose of these sports-specific measures is to measure the attributes that are commonly required during many sports (strength, speed, agility, power, etc.) in hopes of predicting performance ability in an actual game or match. There is no way to predict athletic performance in measures such as points per game, assists per game, etc., but the general thought behind sport-specific measures is that the better scores achieved might relate to increased athletic performance (i.e. faster athletes have better athletic performance).

In the current study, the medicine ball throw was performed in a tall-kneeling position and the participants were prohibited from falling forward after the throw which required isometric control of the core muscu-

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<th>Event (Best Score)</th>
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<td>Medicine Ball Throw</td>
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*Statistically significant

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<th>Event (Best Score)</th>
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*Statistically significant

Table 4. Correlation between leg lowering and performance tests, top performers (n = 18)

Table 5. Correlation between leg lowering and performance tests, bottom performers (n = 17)

Table 6. Test of between-subjects effects, using ANOVA
lature. By performing the test in this manner participants were required to stabilize their trunks while performing an explosive upper extremity countermovement. The other tests used did not focus specifically on stabilizing the trunk and allowed for potential compensation from other non-core muscle groups.

According to data from the current study, males scored higher on the test of core stability on average when compared to females. This is consistent with Leetun et al27 who showed that males have greater core strength compared to females possibly related to bone structure and postural differences in the pelvis. It is possible that core stability may be impacted by the anatomical alignment of the female pelvis which affects the angulation of muscular attachments. Subtle changes in the angle of pull of the core musculature on the pelvis may result in decreased ability to control the trunk. Brophy et al40 showed that male soccer players have a stronger abdominal strength and thus core control (by their definition) as compared to their female counterparts. Wilson et al41 likewise demonstrated that males had higher normalized and peak isometric muscle torques of the trunk, hip, knee during a 45 degree single-leg squat than females in all studied muscles groups.

Measuring core stability is a difficult task with no test or measure serving as a gold standard. Double-leg lowering is supported in the literature as a valid and reliable measure of core strength.33-35 Unfortunately, the function of the core musculature during athletic performance may not be accurately quantified by a stationary, uniplanar test. It seems that it may be more appropriate to use a dynamic measure of core stability which mimics complex, explosive, multiplanar movements. However, at the current time, the literature does not offer a reliable and valid measure that fits these criteria. Functional movements require both mobility and stability within the kinetic chain and would seem to be a reasonable method for comparing core stability and performance because they are dynamic in nature.42 However, Okada et al42 showed that at best, only weak relationships are seen between core stability and functional movements and no significant relationship were present to the Functional Movement Screen. This suggests that functional movement screens may be somewhat limited as to their ability to predict athletic performance.

Core stability is a broad construct that includes proprioceptive control, strength, power, and endurance. Tests need to be determined for each of these subcategories because it remains unclear as to which element may be the most important for different sports, as well as which best reflects the combination of tasks related to sport participation. A creation of a gold standard test or test battery would greatly enhance the current knowledge of and the ability to study the relationship between core stability and athletic performance.

Possible limitations in this study include the absence of height and weight measurements for the subjects used in the study. It could be possible that relationships exist between these variables and core stability. The population used in this study may have also impacted the results of the data. A small sample of volunteers with similar demographics and a limited variety of sports were examined. The motivational component of the participants’ performance was not measured and may have played a role in test outcomes; some may have been more or less motivated to perform at their greatest ability. The athletes were participants in NAIA-Division II athletics and possibly do not reflect elite athletic performers. The greatest limitation in the study revolves around a lack of a gold standard to measure core stability. The DLL test used in this study measures strength in the sagittal plane but does not measure muscle endurance, proprioception, or other key multiplanar musculature thought to control the core. Future researchers should attempt to include larger samples, a greater variety of sports (as there may be other activities that require greater core control), elite athletes, and a more demographically diverse sample.

CONCLUSION

The results of this pilot study suggest that a significant, although fair or weak relationship exists between the double leg lowering test as a measure of core stability and the medicine ball throw. Top performers demonstrated a stronger, significant correlation between these tests as compared to bottom performers. The data demonstrated that males, on average, scored better on the test of core stability as compared to females. These results provide the basis for future research, but do not provide answers to
many of the unknown questions concerning the relationship between core stability and athletic performance. Future researchers should seek to identify a gold standard test or battery of tests that quantifies core stability as it pertains to athletic performance. Also, the specific functions of the core, such as stability, strength, or endurance, should be examined separately to determine the relative importance of each. Additional research should focus on specific sports and actual sports performance outcomes such as points per game, goals scored, etc. but also include maximal performances ideally linked to the activity of choice (i.e.-ball speed or distance if related to throwing). It also would be beneficial to examine the relationship between core stability and additional athletic performance tests. The body of literature concerning athletic performance and core stability continues to evolve, but many essential questions remain unanswered. Until the relationship between core stability and athletic performance can be scientifically demonstrated the in the evidence, it will remain hypothetical and theoretical in nature.

REFERENCES:


ABSTRACT

Background: The Functional Movement Screen™ (FMS™) is a screening instrument which evaluates selective fundamental movement patterns to determine potential injury risk. However, despite its global use, there are currently no normative values available for the FMS™.

Objectives: To establish normative values for the FMS™ in a population of active, healthy individuals. Secondary aims were to investigate whether performance differed between males and females, between those with and without a previous history of injury, and to establish real-time inter-rater reliability of the FMS™.

Methods: Two hundred and nine (108 females and 101 males) physically active individuals, aged between 18 and 40 years, with no recent (<6 weeks) history of musculoskeletal injury were recruited. All participants performed the FMS™ and were scored using the previously established standardized FMS™ criteria. A representative sub-group participant sample (28%) determined inter-rater reliability.

Results: The mean composite FMS™ score was 15.7 with a 95% confidence interval between 15.4 and 15.9 out of a possible total of 21. There was no statistically significant difference in scores between females and males ($t_{207} = .979, p = .329$), or those who reported a previous injury and those who did not ($t_{207} = .688, p = .492$). Inter-rater reliability (ICC$_{3,1}$) for the composite FMS™ score was .971, demonstrating excellent reliability. Inter-rater reliability (Kappa) for individual test components of the FMS™ demonstrated substantial to excellent agreement (0.70 — 1.0).

Discussion and Conclusion: This cross-sectional study provides FMS™ reference values for young, active individuals, which will assist in the interpretation of individual scores when screening athletes for musculoskeletal injury and performance factors.

Key words: Pre-participation screening, Functional Movement Screen™, injury risk, athletic performance.

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INTRODUCTION
Pre-participation and pre-season athletic screening procedures are well established components of international sport programs, and are utilized to identify potential risk factors that might lead to injury and illness such as cardiac disease, head injury, and specific musculoskeletal problems. Screening procedures can also be used in injury prevention in order to counsel individuals with sport specific functional deficits, create individual pre-habilitation or rehabilitation programs and to enhance sporting performance. Originally, screening procedures were sport specific and often focused on identifying factors that would exclude a person from participating in certain activities or were used to identify specific athletic talent. However, the common misconception that screens by themselves can prevent injury has been challenged because they only provide individual information that is often based on standardized exercise recommendations, and may or may not suit an athlete’s specific needs.

More recently, athletic screening has shifted towards a more functional approach based on the assumption that identifiable biomechanical deficits in fundamental movement patterns have the potential to limit performance and render the athlete susceptible to injury. Assessing basic fundamental movement provides an opportunity to create a more individualized training program that focuses on changing or modifying movement patterns, instead of focusing on the rehabilitation of specific joints and muscles.

One of the new generation of screening assessments which evaluates functional movement patterns is the Functional Movement Screen (FMS). The FMS was developed as a comprehensive pre-participation and pre-season screen, and consists of seven tests/movements which challenge an individual’s ability to perform basic movement patterns that reflect combinations of muscle strength, flexibility, range of motion, coordination, balance and proprioception. The primary goal of the FMS is to evaluate the body’s kinetic chain system, where the body is evaluated as a linked system of interdependent segments, which often work in a proximal to distal direction to initiate movement. The FMS provides information that indicates if an athlete has problems with stabilization and/or mobility. This provides the foundations for an informed prescriptive training program developed with a focus on creating sound movement patterns. Five of the seven FMS tests are scored separately for the left and right sides, and can therefore be used to locate asymmetries which have been identified as an injury risk factor. An FMS specified cut-off value of 14 or below is suggested to indicate an elevated risk of injury. This value was derived from a study of professional football players by utilizing information from a Receiver Operator Characteristic (ROC) curve which maximized the sensitivity and specificity of the test. It is important to note that this study had a relatively small sample size (N = 46) and, along with the fact that only one sport was evaluated, the ability to generalize this cut-off value to other sport and recreation participants may be limited. The FMS has been utilized to evaluate and reduce injury risk in specific occupational groups (e.g. firefighters), and used in sports teams to screen pre-season for injury risk and to develop specific intervention programs to prevent injuries.

To date, there are no published normative values for score on the FMS to help sports physical therapists, coaches, and athletic trainers interpret the raw data collected during testing. The availability of reference values would enhance the use of the FMS by allowing comparison of an athlete’s score with normative reference values. It is also considered important to gain a better understanding of the instrument and the performance of the individual tests in order to assist in the development of robust psychometric properties associated with the instrument. Only a minimal amount of information on the psychometric properties of the FMS has been published to date. The inter-rater reliability of the FMS, established via analysis of video data, is high. The purpose of this study was to establish normative values for the FMS in a population of healthy active individuals. Secondary aims were to investigate whether performance differed between males and females, between those with and without a previous history of injury, and to establish real-time inter-rater reliability of the FMS.
METHODS

Subjects
The study employed a prospective cross-sectional design with an included reliability component. A convenience sample of approximately 200 healthy females and males aged between 18 and 40 years was targeted and recruited from a tertiary student population (University & Polytechnic), sports clubs and the general public within the greater southern region of New Zealand. Subjects were included in the study if they participated in regular physical activity at a competitive or recreational level. Exclusion criteria included; the use of a mobility aid or a prophylactic device (e.g. knee brace), or if they had reported a recent (< 6 weeks) musculoskeletal or head injury which was likely to affect their motor performance on the FMSTM. The study was approved by the University of Otago Human Ethics Committee, and written informed consent was obtained from all subjects prior to data collection.

Data Collection Procedures
Subjects were recruited via advertising on community notice boards, announcements in university classes, direct contact, and word of mouth. Data collection took place between September and October 2010 in a university human movement testing laboratory or in a Physical Therapy clinic located at the university recreation center. The participants were asked to wear their usual athletic clothing and footwear for the study. The data were collected by two members of the research team (ÅD, EH) who worked with members of the extended research team to establish a data collection protocol. This included in-house training sessions in the administration and scoring of the FMSTM, review of relevant literature, studying a training video and related documentation, and working with several members of the research team, which resulted in standardized data collection procedures. A pilot study was conducted with 10 participants in order to achieve a reliable level of agreement between the two test raters which resulted in Kappa values > .70 for all tests.

After providing written informed consent, and prior to testing, each subject completed a short questionnaire regarding their injury history, usual physical activity levels, and demographic information. Each participant's weight was measured in kilograms and height in centimeters.

Limb dominance was measured to generate descriptive information about the subjects and to describe any asymmetry during testing. Four short tests which have been shown to provide a valid measure of footedness were conducted. The leg used to perform the tests was considered to be the dominant leg. Data from these tests were used to compute a lower limb Laterality Quotient (LQ), defined as: the number of tasks performed with the left leg subtracted from the tasks performed with the right leg, divided by the number of tasks. The LQ has potential scores ranging from —1 (left foot dominant) to +1 (right foot dominant). Upper limb preference was determined by observing which hand the subject used to write on the questionnaire.

The Functional Movement Screen™, developed by Cook and Burton, was used in the study. The test administration procedures, instructions and scoring process associated with the standardized version of the test were followed in order to ensure the scoring accuracy. Each participant was given three trials on each of the seven tests (deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push-up and rotary stability). Each trial was scored on a scale from 0 to 3. A score of 0 indicated that pain was reported during the movement; 1 indicated failure to complete the movement or loss of balance during the movement; 2 completion of the movement with compensation; and 3 performance of the movement without any compensation. For each item, the highest score from the three trials was recorded and used to generate an overall composite FMSTM score with a maximum value of 21. For the tests that were assessed bilaterally, the lowest score was used. Three of the tests (shoulder mobility, trunk stability push-up and rotary stability) also have associated clearing exams that are scored as either positive or negative with a positive response indicating that pain was reproduced during the examination movement.

In order to establish that both raters who collected the study data scored the subjects in a similar manner, an inter-rater reliability component was included in the study design. Both raters were equal in terms
of clinical experience and their previous use of the FMS™. A sample of convenience was used to select subjects considered to be representative of the main study sample, and these were scored simultaneously and independently (without consultation) by the two raters. The same rater instructed all the subjects during the collection of the reliability data.

**Data Analysis**

In order to provide a comprehensive description of the participants and the FMS™ data; means, standard deviations, 95% confidence intervals (CI), and frequencies were computed for males and females separately, and for all participants combined. Where appropriate, independent t-tests were used to examine for potential differences between males and females, and between those who had and had not sustained an injury in the previous 6 months, with the exact probability values presented. The number of participants who scored at or below the cut-off value of 14 was tabulated. Chi-square tests were used to evaluate if there were any significant differences between males and females in the distribution of scores for the different tests. The Intra-class Correlation Coefficient (ICC model 3,1) was the reliability statistic used to establish the inter-rater reliability for the FMS™ composite score, and the unweighted Kappa statistic was used to establish the inter-rater reliability measurement for each item. The inter-rater reliability data were interpreted according to the categories defined by Landis and Koch. A Kappa value over 80% represents excellent agreement; above 60% substantial level of agreement, 40-60% moderate level of agreement, and below 40% poor to fair agreement. All calculations were performed using SPSS (version 16.0) and the a priori level of significance was set at p ≤ 0.05.

**RESULTS**

Two hundred and nine subjects participated in the study, 108 females (mean age 21.2, height 166.5 cm, weight 66.4 kg and BMI 23.9), and 101 males (mean age 22.7, height 178.5 cm, weight 79.7 kg and BMI 25.0). The descriptive data are presented in Table 1. All subjects were free from injury at the time of testing, however, 50 subjects reported having sustained an injury in the previous 6 months from which they had recovered, and were participating in a range of physical activities. Sixty-five percent of the subjects met the American College of Sport Medicine (ACSM) and American Heart Association (AHA) basic recommendations for age related exercise; meaning

<table>
<thead>
<tr>
<th>Variable</th>
<th>Combined</th>
<th>Females</th>
<th>Males</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>95% CI</td>
<td>Range*</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>21.9 ± 3.7</td>
<td>21.4 - 22.4</td>
<td>18 - 40</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>72.8 ±12.3</td>
<td>71.1 - 74.5</td>
<td>40 - 118</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>172.3 ± 9.0</td>
<td>171.1 - 173.5</td>
<td>150 - 192</td>
</tr>
<tr>
<td>BMI</td>
<td>24.4 ± 3.1</td>
<td>24.0 - 24.9</td>
<td>17 - 35</td>
</tr>
<tr>
<td>LQ‡</td>
<td>0.8 ± 0.5</td>
<td>0.7 - 0.9</td>
<td>(-1) - 1.0</td>
</tr>
</tbody>
</table>

| Numbers | Arm dom§ | | |
|---------|---------| | |
|        | 19 left | 7 left | 12 left |
|        | 190 right | 101 right | 89 right |

* min - max, † difference between females and males, ‡ Footedness laterality quotient, §dominance
Table 2. Inter-rater reliability for individual FMS™ tests.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Agreement %</th>
<th>Kappa</th>
<th>Level of agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep squat</td>
<td>100</td>
<td>1.00</td>
<td>Excellent</td>
</tr>
<tr>
<td>Hurdle step R*</td>
<td>86</td>
<td>0.70</td>
<td>Substantial</td>
</tr>
<tr>
<td>Hurdle step L†</td>
<td>91</td>
<td>0.77</td>
<td>Substantial</td>
</tr>
<tr>
<td>Hurdle step final</td>
<td>93</td>
<td>0.80</td>
<td>Substantial</td>
</tr>
<tr>
<td>In-line lunge R</td>
<td>88</td>
<td>0.73</td>
<td>Substantial</td>
</tr>
<tr>
<td>In-line lunge L</td>
<td>90</td>
<td>0.79</td>
<td>Substantial</td>
</tr>
<tr>
<td>In-line lunge final</td>
<td>93</td>
<td>0.86</td>
<td>Excellent</td>
</tr>
<tr>
<td>Shoulder mobility R</td>
<td>97</td>
<td>0.91</td>
<td>Excellent</td>
</tr>
<tr>
<td>Shoulder mobility L</td>
<td>93</td>
<td>0.87</td>
<td>Excellent</td>
</tr>
<tr>
<td>Shoulder mobility final</td>
<td>97</td>
<td>0.94</td>
<td>Excellent</td>
</tr>
<tr>
<td>Active straight leg raise R</td>
<td>90</td>
<td>0.84</td>
<td>Excellent</td>
</tr>
<tr>
<td>Active straight leg raise L</td>
<td>90</td>
<td>0.84</td>
<td>Excellent</td>
</tr>
<tr>
<td>Active straight leg raise final</td>
<td>97</td>
<td>0.94</td>
<td>Excellent</td>
</tr>
<tr>
<td>Trunk stability push-up</td>
<td>100</td>
<td>1.00</td>
<td>Excellent</td>
</tr>
<tr>
<td>Rotary stability R</td>
<td>100</td>
<td>1.00</td>
<td>Excellent</td>
</tr>
<tr>
<td>Rotary stability L</td>
<td>100</td>
<td>1.00</td>
<td>Excellent</td>
</tr>
<tr>
<td>Rotary stability final</td>
<td>100</td>
<td>1.00</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

* Right, † Left, ‡ Landis & Koch, 1977

that they performed moderate-intensity aerobic (endurance) physical activity for a minimum of 30 min on five days each week or vigorous-intensity aerobic physical activity for a minimum of 20 min on three days each week.23

The inter-rater reliability (ICC) of the composite score for both testers was .971 which indicates excellent reliability. The inter-rater reliability (Kappa) for each score of the individuals' right and left side performance and for the final score for each test is presented in Table 2. Six of the seven final scores demonstrated excellent agreement and six of the ten right and left side scores also showed excellent agreement. The remaining scores demonstrated substantial agreement between the two raters.

All of the subjects completed the entire FMS™. One individual reported pain on the in-line lunge, two on the shoulder mobility test, and three on the trunk stability push-up, which resulted in a score of zero for these tests items. The descriptive data for the FMS™ and its composite items are presented in Table 3. The combined composite mean score on the FMS™ was 15.7 with a standard deviation on 1.9 and a median of 16. The 95% confidence interval was 15.4 to 15.9 and the range was from 11 to 20. The mean for the composite score for the females was 15.6 and for the males 15.8, although this difference was not statistically significant (p > .05). Sixty five individuals (29 males and 36 females), representing 31% of the participants, had a composite score of 14 or below which indicates a heightened risk of injury according to Kiesel et al.12

Figure 1 describes the distribution of scores for the different FMS™ tests. A number of scoring patterns are of note. The active straight leg raise (χ² = 42.097, p = .000), the trunk stability push-up (χ² = 64.475, p = .000) and shoulder mobility test (χ² = 17.238, p = .001) had a significant different pattern of scoring for females and males. Females were more flexible on the active straight leg raise with 46.3% (50/108) scoring a `3´, and 43.5% (47/108) scoring a `2´. The majority of males (48.5%, 49/101) scored a `2´ on this test, with 40.6% (41/101) scoring a `1´. The shoulder mobility scores also indicated that females were more flexible than males; and while both males and females had the largest percentage of participants on score `3´, the males' scores were more widely distributed across the scoring spectrum. For the trunk stability push-up movement, the majority of males (76.2%, 77/101) recorded a score of `3´, while for the females the majority (58.3%, 63/108) scored a `1´. These results demonstrate the strength demand of this test, including stability and neuromuscular control, which males were better able to perform than females. For the rotary stability test 88.0% (184/209) of all the participants were scored as a `2´, 11.0% (23/209) a `1´ and 1.0% (2/209) `3´. The rotary stability test also demonstrated a significantly different scoring pattern between males and females (χ² = 7.230, p = .027), which indicates that males have a better core stability than females. No other Chi-squared tests reached statistical significance. An independent sample t-test demonstrated no significant differences on the composite score between individuals who had an injury during the 6 last months and for those who had not (t_{207} = .688, p = 0.492).

Table 3. The composite FMS™ Scores for the combined group (N=209), females (N=108), and males (N=101).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
<th>95% CI</th>
<th>Range*</th>
<th>t_{df}†</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score</td>
<td>Combined</td>
<td>15.7 ± 1.9</td>
<td>15.4 - 15.9</td>
<td>11 - 20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Females</td>
<td>15.6 ± 2.0</td>
<td>15.2 - 15.9</td>
<td>11 - 20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Males</td>
<td>15.8 ± 1.8</td>
<td>15.5 - 16.2</td>
<td>12 - 20</td>
<td>979</td>
</tr>
</tbody>
</table>

* min - max, † difference between females and males

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DISCUSSION

The FMS™ is a screening instrument which evaluates selective athletic movement patterns to determine potential injury risk. To date, there have been no reference data available to assist sports physical therapists, coaches, and athletic trainers to interpret and compare individual data generated from the FMS™. This study provides data on a sizeable group of recreationally and competitively active males and females and shows the FMS™ evaluation process to have substantial to excellent inter-rater reliability.22

There was no significant difference for composite scores between females and males, indicating that the FMS™ can be used to compare individuals in mixed populations. This is an important finding because the majority of published research on the FMS™ has been conducted either exclusively12,16 or predominantly17,18 on males.

The mean composite score reported in this study is slightly lower than that reported for a group of professional male football players (16.9).12 It might be expected that professional football players score better than the average athlete due to their intensive training regimens, however, in a subsequent study on a similar cohort the mean pre-intervention composite score was 11.8 for “lineman” and non-lineman.16 The difference may relate to the cohort studied, the specific training regimens undertaken by each team or familiarity with the FMS™ testing procedures. Cowen17 studied male and female firefighters whose mean baseline FMS™ score was also lower than our current study at 13.25. In the latter two studies the composite FMS™ score significantly increased following an exercise-based intervention.

It is important to note that while there was no difference in this current study for mean composite scores for males and females, significant differences were apparent between females and males on four individual FMS™ tests. Males were on average better on the trunk stability push-up and the rotary stability tests than females, and females performed better on the active straight leg raise and the shoulder mobility items. The trunk stability push-up is associated with upper body strength and stability (including core stability in the sagittal plane), the rotary stability test with transverse plane (rotational) core stability, the active straight leg raise with flexibility in the hamstring muscles, and the shoulder mobility test with range of motion in the shoulder complex and thoracic spine.14 The sex differential finding is supported by Kibler et al. who demonstrated that males were significantly stronger than females, and that females were significantly more flexible than males3 in a study that investigated 2107 athletes from a variety of sports inclusive of junior high to college levels.

The rotary stability test was distinctive from the other FMS™ tests in that very few subjects were able...
to obtain the maximum score of 3, with the majority scoring a 2. This test demands trunk stability in the sagittal and transverse planes during asymmetric movement of the upper and lower extremities. The FMS training manual comments that it is difficult to obtain a score of 3 (only 2 subjects did so in the present study) but it is included to capture elite performance. It is questionable if this test serves a practical role in a screen for the general athletic population and future versions of the FMS may need to consider its continuing inclusion. The rotary stability test does however provide the potential to measure change following a specific exercise training program targeted at asymmetric or multiplanar trunk stability.

In this study 31% of the participants had a score of 14 or less which might indicate a potentially higher risk of injury. This is in comparison to the 22% of the professional football players in the Kiesel et al. study (2007) and 89% in the subsequent study by Kiesel et al. (2009). The cutoff score of 14 was determined in a study on 46 professional football players but, because of the small sample size and the fact that the target group didn't represent a general athletic population, the authors of the current study suggest that this cutoff value should be used with caution. Further studies need to be conducted on other athletic and occupational groups before determining a substantiated cutoff value.

The current study included a real-time, observational, inter-rater reliability component and the data demonstrated excellent or substantial agreement on all parts of the FMS. This is useful as it allows for different individuals to be involved in the data collection when the screen is being administered to large groups. Despite some subtle differences in methodology, this result is similar to that reported in the only other published study on FMS inter-rater reliability. In reliability studies that use video analysis, the focus is mainly on the scoring of data which have been previously collected. In the present study both raters were required to score the subjects in real-time, with no opportunities for a replay of the performance; this is more likely to happen in a real-life setting. In this study the raters had received comparative training in the administration and scoring of the FMS movements and had also developed an appreciation of the movement scoring by working together during data collection for the majority of the cohort. These factors might have influenced the results. The intra-rater reliability and test-retest stability of the FMS also needs to be established if it is to be used to monitor exercise interventions with confidence.

A major strength of this study was the large number and comprehensive descriptive profile of the participants, which allowed both meaningful comparisons between females and males and the potential to make useful future comparisons with similar studies. The provision of a normative dataset with narrow confidence intervals provides sports physical therapists, coaches, and athletic trainers with a reference standard to compare their individual data within a young healthy population. A limitation of this study was that there was no stratification based on the individuals' sport and exercise participation which reduces its ability to be generalized to specific sporting environments, however, this can conversely be seen as a strength of the study when general mass screening of individual athletes of different abilities is required. Another limitation related to the sample studied is that it only focuses on physically active college age athletes. Strength, flexibility and balance/stability all decrease with increasing age, particularly after the 4th decade, and for this reason it is important that this data is not used to make comparisons with, or draw conclusions regarding older athletes. Future research should target specific age groups as well as explicit sporting groups, such as gymnasts and dancers, who may have altered movement patterns as a result of their training and may challenge the test scoring system via a ceiling effect. Further studies could also generate reference data for a younger population of elementary to high school age that are entering their competitive sport career pathway and may have limited injury exposure. This may be useful in working to reduce injury rates in the emerging athletes.

**CONCLUSION**

This research is the first to provide reference data for the FMS on a large general cohort of competitive and recreational exercise participants. These normative data can act as a reference standard for sports physical therapists, coaches and athletic trainers in order to allow meaningful comparisons between
individual sport and exercise participants. Future research is recommended to further refine and validate the FMSTM as a screening tool that can be used in multiple sporting, recreational, and occupational settings.

INSTITUTIONAL REVIEW BOARD
The study was approved by the University of Otago Human Ethics Committee (Ref: 10/118).

ACKNOWLEDGEMENTS
The authors would like to thank Peter Gallagher and Sonya White for their invaluable contributions to the development of this study.

REFERENCES
ABSTRACT

Purpose/Background: Various doses of topical menthol are commonly applied prior to, during, and after exercise to relieve pain although there is limited empirical evidence examining the physiological effects of this treatment. The purpose of this study was to examine the effects of two different doses of menthol (3.5% and 10%) on blood flow and arterial diameter before and after an acute bout of three isokinetic maximum voluntary muscular contraction (MVMC) of the quadriceps and hamstrings.

Methods: Blood flow and arterial diameter of the right and left popliteal arteries were measured with an ultrasound Doppler prior to and after subjects completed 1 set of 3 MVMC isokinetic knee extension/flexion exercises. Immediately following this exercise one of three different treatment conditions was randomly applied to the right thigh only; 3.5% menthol gel, 10% menthol wipe, or a control condition. Five minutes following the treatment application blood flow through both right and left popliteal arteries was reassessed. This procedure was completed once per week until each of the 16 subjects was exposed to each treatment condition.

Results: Repeated measures ANOVA with post hoc analysis indicated that both menthol dosages resulted in significant decreases in popliteal blood flow on the right (−19.60 to −8.39%) and left sides (−14.72 to −5.4%) while the control condition demonstrated an increase in blood flow bilaterally (+26.40 to +15.19%) as a result of the MVMC exercise. The right popliteal arterial diameter was also significantly reduced as a result of both menthol dosages (−5.73 to −6.73%) and increased under the control condition (+6.67%).

Conclusion: These results indicate that topical menthol has a rapid effect on reducing ipsilateral and contralateral arterial blood flow as well as ipsilateral arterial diameter.

Levels of Evidence: 2a
INTRODUCTION
The active ingredient in many over the counter pain topical gels is menthol. Menthol is a terpene compound that when applied to the skin in varying doses causes anti-nociceptive and counterirritant sensations, resulting in a soothing sensation for the discomfort of burns, muscle soreness, and joint pain.1-3 Menthol also generates the sensation of cold secondary to thermoreceptor excitation4-9 of the transient receptor potential (TRP) family of ion channels. TRP's are located throughout the body and TRP melastatin 8 (TRPM8) thermosensitive neurons have been found to be particularly sensitive to menthol stimulation.10-15 Previous authors have reported that stimulating thermoreceptors by lowering the temperature of the surrounding tissues results in vasoconstriction and a reduction in blood flow to the surrounding tissues. Hodges et al reported that stimulating thermoreceptors through localized cooling inhibited the release of nitric oxide synthase (NOS) from the endothelial cells that line the vascular smooth muscle (VSM), resulting in vascular constriction.16 Stimulating thermoreceptors through localized cooling has also been reported to activate the α2-adrenergic receptors via sympathetic reflex of the muscle afferents, creating arterial vasoconstriction.17-20 Localized cooling of the skin that stimulates thermoreceptors elicits both local and generalized vasoconstriction. The magnitude of both of these vasoconstriction responses is, in part, dependent on declines in core temperature resulting from cooling of the periphery.21

Although menthol stimulates thermoreceptors that have been found to result in vasoconstriction with localized cooling, a limited number of studies have examined the vaso-reactive responses stimulated by topically applied menthol. Olive et al.22 demonstrated that the topical application of 3.5% menthol gel to the forearm had a similar effect as applying ½ kg of crushed ice on reducing blood flow by an average of 24% through the brachial artery approximately 10 cm proximal to the treatment for up to 10 minutes following application. Another previous study reported that a 3.5% menthol gel or ½ kg of crushed ice applied to the forearm resulted in decreases in radial arterial blood flow distal to the treatment application.23 Radial arterial blood flow decreased within the first 5 minutes of applying the menthol and slowly returned to pretreatment levels over 20 minutes.23 The ice treatment in this trial resulted in a decrease in blood flow at 15 minutes following the application. These results suggest topical menthol and ice can significantly decrease blood flow with menthol resulting in a fast acting but short lived reduction in blood flow while the application of ice requires a longer application to achieve a similar vasoconstrictive effect.

High intensity-short duration exercise results in increases blood flow to the involved tissues.24 Topical menthol has been found to relieve pain25 and is commonly applied prior to, during, and following exercise. No study has examined the vasoactive effects of different doses of topical menthol applied immediately following a bout of high intensity (100% effort), short duration isokinetic muscle flexion/extension exercise (3 maximum repetitions). The purpose of this study was to examine the effects of two different doses of menthol (3.5% and 10%) on blood flow and arterial diameter before and after an acute bout of three isokinetic maximum voluntary muscular contraction (MVMC) of the quadriceps and hamstrings. It was hypothesized that the application of either 3.5% or 10% menthol to one of the thighs would result in a decrease in blood flow and arterial diameter in the ipsi- and contra-lateral limb popliteal artery following a bout of three maximum voluntary muscular contractions (MVMC).

METHODS
This research protocol was submitted to, and approved by the Institution's Human Subjects Review Board. A convenience sample of sixteen subjects, 8 males and 8 females (Table 1) with no pre-existing cardiovascular or peripheral vascular disorders provided written consent prior to participating in four 1-hour sessions in the laboratory. Each session was separated by approximately 1 week to allow a ‘wash-out’ period between intervention exposures and data collection sessions. Session 1 oriented the subjects to the testing procedures. During this first session subjects were introduced to the maximum voluntary muscle leg extension and flexion exercise (MVMC procedure) using the Biodex System 3 (Shirley, NY) dynamometer and the popliteal blood flow data collection protocol using the Philips HDI 5000 Ultrasound Doppler (Seattle, WA). When performing the
MVMC procedure subjects were instructed to exert a “maximum effort” when performing three repetitions of the exercise. Maximum voluntary muscle contraction was determined when the peak torque measures for leg extension and flexion varied by no more than 5%. Sessions 2 through 4 involved the random application of one of three treatment conditions and data collection taking place prior to and following each treatment condition.

During data collection sessions, one of three randomly selected treatment conditions was applied to the right thigh distally from the inguinal and gluteal folds to the superior margin of the patella and popliteal fossa. No treatment was administered to the left leg in order to provide a within subject control measure. Treatment conditions were randomly applied at each of the three data collection sessions. Each subject had blood flow data collected on both legs prior to and following each of the three treatment conditions. The treatment conditions included an application of 3.5% menthol gel (BioFreeze® gel, 1 ml of gel for every 200 cm² sq cm of right thigh surface area), the application of two 10% menthol wipes (BioFreeze® wipes) and a control condition which consisted of no treatment. The amount of 3.5% menthol applied to a subject’s right thigh averaged 7.0 ± 1.1 mL. Pilot studies determined that 2 wipes were sufficient to pass over all areas of the entire thigh one time which provided a similar coverage during this treatment condition as was achieved with the 3.5% menthol gel. The menthol wipes were administered from a pre-packaged commercially available packet consisting of a saturated cotton wipe measuring 15 cm x 15 cm.

During data collection subjects reported to the laboratory at approximately the same time of day and were placed in a seated position and told to rest quietly for 10 minutes prior to any data collection to allow a consistent baseline for data collection. Heart rate (b/min) and blood pressure (mm/Hg) were assessed by the same researcher at all data collections using an automated blood pressure cuff (OMRON, Kyoto, Japan) on the right arm immediately prior to all blood flow measures. Subjects were then instructed to lie in a prone position on a padded table which allowed visualization of the popliteal fossa of both legs. Blood flow assessments were taken from right to left so as to standardize data collection. While prone, the popliteal artery was palpated in the popliteal fossa medial to the biceps femoris and lateral to the semitendinosus muscle. The popliteal artery was selected for this study since it was immediately distal to the treatment application site. Once the vessel was palpated, the Doppler sensor head was positioned over the artery until the vessel could be accurately visualized on the device’s video screen. The popliteal artery was imaged longitudinally, by B-mode ultrasound, using a 12-5 MHz linear array transducer using high-resolution ultrasound (Philips HDI 5000, Seattle, WA). A video file of the ultrasound was

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<th>Table 1. Subject demographics</th>
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<td>Age (years)</td>
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<td>Height (cm)</td>
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<tr>
<td>Weight (kg)</td>
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<tr>
<td>Resting Heart Rate (bpm)</td>
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<td>Resting Systolic BP (mmHg)</td>
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<tr>
<td>Resting Diastolic BP (mmHg)</td>
</tr>
<tr>
<td>Body Fat Percentage (%)</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
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<tr>
<td>Hips circumference (cm)</td>
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<tr>
<td>Aerobic Exercise (min/wk)</td>
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<td>Resistance Exercise (min/wk)</td>
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collected over five pulsations (or heart beats) and were analyzed by the HDI 5000 internal software. This analysis yielded average vessel volume (ml/min) and maximum diameter (cm/beat) in the popliteal artery at baseline and the subsequent data collection points within each session. This method of estimating blood flow has been reported to have strong validity (r=.96–.98) when calculating blood flow in different vessel compartments. This same protocol was repeated on the left leg immediately following collection of blood flow and vessel diameter on the right side. This assessment of blood flow and vessel diameter of both the right and left popliteal arteries was completed again following the MVMC exercises at approximately 5 minutes following the application of each of the three treatment conditions. The same technician completed all data collection.

Immediately following the baseline blood flow data collection subjects were asked to perform three knee extension/flexion MVMC exercises on a Biodex System 3 isokinetic dynamometer. Subjects were seated upright with restraints applied to their waist, torso, and right thigh. The axis of rotation of the dynamometer was placed at the lateral condyle of the tibia with the rotational arm attached to a pad at the terminal end of the anterior tibia with a strap wrapping around the posterior of the limb. Each subject's passive knee extension and flexion range of motion was determined. Subjects were then allowed to familiarize themselves with three submaximum knee extension/flexion exercises through their passive range of motion at a rotation speed of 90 degrees per second using the isokinetic dynamometer. Subjects were then asked to complete 3 repeated maximum flexion and extensions of the knee at a rotation speed of 90 degrees per second which is a commonly employed protocol to assess isokinetic leg strength. Following this exercise on the right the MCMV procedure was repeated on the left side. Immediately following the MVMC exercises one of the three treatment conditions were randomly applied to the subject's right thigh. Since MCMV was not assessed in both legs simultaneously there was a slight difference (approximately 2 minutes) in the duration between performing the exercise and measuring blood flow on the right and left side. This protocol was developed to simulate a high intensity-short duration exercise in order to stimulate blood flow to the thigh and distally through the popliteal artery.

STATISTICAL METHODS
Outcome data to address the study hypothesis were analyzed using SPSS statistical (version 18.1) software. Repeated measures analysis of variance (ANOVA) were used to determine the time (baseline vs. 5-minute post treatment), treatment (3.5% menthol, 10% menthol vs. control), and interaction of time and treatment on popliteal arterial diameter and blood flow. Significant main and interaction effects (p < .05) were further addressed by using Tukey’s least significant differences (LSD) post hoc comparisons between means.

RESULTS
Analysis indicated a significant (F = 15.43, p = .00) time effect on heart rate, with no significant treatment or interaction effects. Post hoc analysis indicated that the 3.5% menthol and control conditions resulted in a significant drop in heart rate of 4.63 and 5.19 beats/min respectively while the 10% menthol condition did not affect heart rate over the course of the trial. Heart rate was not different between the three treatment conditions at baseline or at 5 minutes post treatment application. The analysis also indicates no significant time, treatment, or interaction effect of any of the three treatment conditions on diastolic or systolic blood pressure.

A significant interaction (F = 11.48, p = .00) was observed on blood flow in the right popliteal artery, the side receiving the treatments (See Table 2). Post hoc analysis revealed a decrease in blood flow during the 3.5% and the 10% menthol treatments, while blood flow during the control treatment significantly increased through the right popliteal artery. Blood flow through the right popliteal artery was similar at baseline before application between each of the three treatment conditions. At 5 minutes following application of the treatments the control condition resulted in significantly higher blood flow compared to either the 3.5% or the 10% menthol conditions. The blood flow in the right popliteal artery was not different under the two different menthol dosages at 5 minutes post treatment. Analysis of blood flow in the left popliteal artery also resulted in a significant interaction (F = 4.75, p = .01). The post hoc analy-
The results of this study appear to support the hypothesis that the application of either 3.5% menthol gel or 10% menthol wipe to the thigh decreases blood flow in the ipsi- and contra-lateral popliteal arteries following a high intensity-short duration bout of exercise. The application of 3.5% menthol gel or a 10% menthol wipe reduced arterial popliteal diameter on the side receiving these treatments but not in the same vessel on the contra-lateral side.

**DISCUSSION**

The results of this study appear to support the hypothesis that the application of either 3.5% menthol gel or 10% menthol wipe to the thigh decreases blood flow in the ipsi- and contra-lateral popliteal arteries following a high intensity-short duration bout of exercise. The application of 3.5% menthol gel or a 10% menthol wipe reduced arterial popliteal diameter on the side receiving these treatments but not in the same vessel on the contra-lateral side.
stress in the vessel resulting in the release of NOS and nitric oxide (NO) which in turn relaxes the adjacent vascular smooth muscle increasing arterial diameter thereby allowing greater blood flow through the vessel. Following the MVMC subjects when receiving the control treatment demonstrated significant increases in popliteal artery blood flow (16-27% bilaterally) and a significant increase in popliteal artery diameter on the right side only. The anticipated increase in arterial diameter and blood flow following a bout of exercise appears to be dampened or reversed during the application of the 3.5% menthol gel and 10% menthol wipes. One explanation for this result is the increased adrenergic stimulation due to the sympathetic reflex which may be associated with menthol application stimulation of TRPM8 thermosensitive neurons similar to the effect of tissue cooling. This explanation is consistent with the findings of other investigators who have also reported that application of topical menthol resulted in dampened or reversed responses.

This hypothesis is further supported in that the effect of the treatments on heart rate and blood pressure were equivocal. The changes in blood flow and arterial diameter observed under the treatment conditions do not appear to be attributed to changes in heart rate or blood pressure. Thus, the effect of the menthol treatments on decreasing blood flow and arterial diameter seem to be similar to the effect of more general tissue cooling, resulting in both local and generalized vasoconstriction as determined by high-resolution ultrasound.

The observed increases in blood flow and to a lesser extent arterial diameter during the control condition were consistent with results reported by previous authors who described increased arterial diameter and blood flow that occurs within muscles during and following exercise by those muscles. This increase in arterial diameter and blood flow during and following exercise is primarily through shearing

<table>
<thead>
<tr>
<th>Condition</th>
<th>Baseline (cm/beat)</th>
<th>5 Minutes Post Treatment (cm/beat)</th>
<th>Raw and Percentage Change (cm/beat, % change)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5% Menthol Gel</td>
<td>.751 ± .15</td>
<td>.708 ± .10*</td>
<td>-.043 (5.73%)</td>
</tr>
<tr>
<td>10% Menthol Wipes</td>
<td>.683 ± .08</td>
<td>.637 ± .08*</td>
<td>-.046 (6.73%)</td>
</tr>
<tr>
<td>Control</td>
<td>.688 ± .11</td>
<td>.734 ± .13*</td>
<td>.046 (6.67%)</td>
</tr>
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</table>

* indicates a significant change within treatment condition over time
Note: Shading indicates a significant difference between treatment and control condition at the specific data collection point

<table>
<thead>
<tr>
<th>Condition</th>
<th>Baseline (cm/beat)</th>
<th>5 Minutes Post Treatment (cm/beat)</th>
<th>Raw and Percentage Change (cm/beat, % change)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5% Menthol Gel</td>
<td>.741 ± .12</td>
<td>.726 ± .13</td>
<td>-.015 (2.02%)</td>
</tr>
<tr>
<td>10% Menthol Wipes</td>
<td>.693 ± .08</td>
<td>.668 ± .06</td>
<td>-.025 (3.60%)</td>
</tr>
<tr>
<td>Control</td>
<td>.702 ± .13</td>
<td>.720 ± .09</td>
<td>.018 (2.56%)</td>
</tr>
</tbody>
</table>

* indicates a significant change within treatment condition over time
Shading indicates a significant difference between treatment and control condition at the specific data collection point

Table 4. Arterial diameter in right popliteal artery by time and treatment condition

Table 5. Arterial diameter in left popliteal artery by time and treatment condition
in decreases in arterial blood flow and decreased arterial diameter.\textsuperscript{16, 31-32} Topical menthol may also excite $\alpha_{2c}$ adrenergic receptors via sympathetic stimulation similar to tissue cooling\textsuperscript{17, 19} which also leads to arterial vasoconstriction. Thus, both doses of menthol application appeared to decrease blood flow in the ipsi-lateral popliteal artery following an acute bout of exercise compared to the control condition which exhibited an increase in blood flow in this vessel following the exercise. This finding that topical menthol decreases local blood flow following acute exercise may be attributed to local inhibition of both NOS and NO and increased $\alpha_{2c}$ adrenergic tone.

This local vasoconstriction effect of topical menthol does not explain the reductions in blood flow observed in the contra-lateral limb which was not directly exposed to the topical menthol treatments. Topical menthol results in a cooling sensation\textsuperscript{25, 33-34} detected by cutaneous cold receptors, which include A-delta and C fibers and has also been postulated to reduce blood flow through neuronal reflex mechanisms.\textsuperscript{23} Menthol is believed to produce this cooling sensation by inhibiting calcium currents of the neuronal membrane\textsuperscript{25} among transient receptor potential family of ion channels or TRP's. Haeseler et al\textsuperscript{2} concluded that the application of topical menthol attenuates local increases in blood pressure during exercise likely through an increase in peripheral resistance at the muscle area\textsuperscript{35-36} leading to a reduction in overall blood flow to the area. It is thought that the reduction in blood flow is due to the inhibition of the small-diameter sensory nerve fibers that are known as group III and IV afferents that synapse with spinoreticular tract neurons in the dorsal horn of the spinal cord.\textsuperscript{35} This spinal reflex initiated through the application of topical menthol appears to have both a local and generalized vasoconstriction effect similar to tissue cooling\textsuperscript{21} but does not rely on changes in tissue temperature. It is suggested by this author that this spinal reflex may account for the changes in blood flow in the contralateral popliteal artery following the application of topical menthol although the mechanism is unclear. This potential generalized vasoconstriction effect of topical menthol warrants further study.

The results appear to indicate that the 10% menthol wipe and the 3.5% menthol gel had a similar effect on blood flow in the ipsi- and contra-lateral popliteal arteries. Although statistically similar, the clinical impact may be different between these two doses of menthol. For example, blood flow was reduced by 19.60 – 17.89% under the 3.5% menthol gel and by 8.31 – 5.40% with the 10% menthol wipe in the ipsi- and contra-lateral popliteal arteries respectively. This finding is curious since it was anticipated a priori that a higher dose or a more concentrated application of menthol would result in a more pronounced effect on blood flow. Closer examination of the two commercially available products employed in this study may explain this outcome. The 3.5% menthol gel and the 10% menthol wipe are delivered through a different medium. The gel contains propylene glycol and glycerol that are not found in the wipes. Studies have shown that propylene glycol and glycerol facilitate absorption through increasing the skin's permeability to topical products.\textsuperscript{37-39} Further, the high alcohol content of the 10% menthol wipe may have increased the rate of evaporation further limiting the absorption rate of the menthol under this condition.

These results must be interpreted cautiously due to a number of limitations with the study design. First, a single artery distal to the application to the two menthol treatments and not the blood flow within the tissues directly adjacent to the treatments was assessed. Thus, the effect of the menthol on the tissues directly adjacent to the treatments was not measured. Second, the local and spinal mechanisms resulting in alterations in blood flow were not directly studied and the possible effect of menthol on these mechanisms is conjectured based upon previous studies. Future studies may examine the possible physiological mechanisms explaining the significant effects of the interventions on the outcome variables. Finally, the sample consisted of a limited number of healthy young adults. This small sample likely limited the statistical power to detect a treatment effect on arterial diameter in the ipsi-lateral artery under the two menthol dosages. The small sample also limited examination of other potentially confounding variables including gender, physical fitness, and dominant versus non-dominant side comparisons. Further, the findings of this study may not be replicable among older populations with chronic health conditions such as diabetes or peripheral vascular disease which may affect blood flow.
CONCLUSION
The findings of this study indicate that topical applications of various doses of menthol to the thigh results in a significant decrease in local (ipsi-lateral popliteal artery) and generalized (contra-lateral popliteal artery) blood flow following a MVMC. These findings possibly indicate that menthol affects blood flow through inhibiting local NOS and NO, and increased increasing systemic \( \alpha_{2c} \) adrenergic tone. Clinicians may apply the findings of this study to support using topical menthol gels or wipes to decrease local blood flow and attenuate the inflammation process following a soft tissue injury. Finally, the local and generalized effect of menthol on blood flow reported in this study warrants further investigation in order to identify the mechanisms of action and to determine the effect of topical menthol on muscle performance.

REFERENCES


ABSTRACT

Purpose/Background: Hip abduction strengthening exercises may be critical in the prevention and rehabilitation of both overuse and traumatic injuries where knee frontal plane alignment is considered to be important. The purpose of the current investigation was to examine the muscular activation of the gluteus maximus and gluteus medius during the double-leg squat (DLS), single-leg squat (SLS), or front step-up (FSU), and the same exercises when an added load was used to pull the knee medially.

Methods: Eighteen healthy females (ages 18-26) performed six exercises: DLS, DLS with load, FSU, FSU with load, SLS, and SLS with load. Integrated and peak surface electromyography of gluteus maximus and gluteus medius of the dominant leg were recorded and normalized. Motion analysis was used to measure knee abduction angle during each exercise.

Results: SLS had the highest integrated and peak activation for both muscles, regardless of load. Adding load, only increased DLS integrated gluteus maximus activation (p = 0.019). Load did not increase integrated gluteus medius or peak gluteus maximus activation. Adding load decreased SLS peak gluteus medius activation (p = 0.003). Adding load increased peak knee abduction angle during DLS (p = 0.013), FSU (p = 0.000), and SLS (p = 0.011).

Conclusions: Overall, the SLS was most effective exercise for activating the gluteus maximus and gluteus medius. Applied knee load does not appear to increase muscle activation during SLS and FSU. DLS with an applied load may be more beneficial in activating the gluteus maximus. Overall, the use of applied loads appears to promote poorer musculoskeletal alignment in terms of peak knee valgus angle.

Level of Evidence: 3

Key Words: Electromyography, injury, lower extremity, muscle activation
INTRODUCTION
Maintaining frontal plane knee alignment during strengthening and neuromuscular training exercises may be important in the prevention and rehabilitation of both overuse and traumatic injuries. Hip abduction strengthening exercises are often utilized in lower extremity rehabilitation programs since they have functional implications in activities of daily living\(^1\) and may facilitate positive outcomes for hip injuries and in knee dysfunction.\(^2,3\) Hewett et al.\(^4\) reported that a six week strength, flexibility, and neuromuscular training program emphasizing the hip musculature resulted in a decreased incidence of knee injuries in female athletes over a single playing season.

During weight bearing activities, the combination of ground reaction forces, ligamentous forces, and muscular/tendon forces throughout all lower extremity (LE) joints are interrelated; therefore, abnormal/excessive stress, inefficient neuromuscular patterns, or muscular weakness at one joint may have an effect on the entire LE kinetic chain. With these combined effects influencing the LE kinetic chain, hip and ankle kinetics and kinematics during weight bearing activities may have a direct impact on knee biomechanics and thus, relate to knee injury risk.\(^5-8\) Heinert et al.\(^9\) reported that females with decreased hip abductor strength demonstrated a greater peak knee abduction angle during stance phase of treadmill running when compared to females with greater hip abductor strength. Hip strength also influences landing mechanics. Lawrence et al.\(^10\) reported that female subjects with greater strength in the hip external rotators demonstrated lower vertical ground reaction forces during single-leg landings when compared to females with weak hip external rotators. These authors also reported a decrease in external knee valgus moments during landing. Leetun et al.\(^11\) reported that athletes who sustained lower extremity injury had weaker hip abduction and external rotation strength than athletes who were uninjured, when strength was measured before the injury occurred. Hip external rotation strength was significantly reduced by 15% for athletes who sustained a lower extremity injury in their investigation. In addition, Jaramillo et al.\(^12\) reported greater weakness in both peak and endurance force in the ipsilateral flexors/extensors and abductors/adductors of the hip musculature of the injured extremity following knee surgery.

Hip abduction strengthening exercises used in exercise include both weight bearing (closed kinetic chain) and non weight bearing (open kinetic chain) activities. These may include sidelying or standing hip abduction and other single-leg standing (SLS) exercises, such as squats, lateral step downs, proprioceptive training, and plyometric activities. SLS activities require hip abductor muscle activation of the weight-bearing side in order to control pelvic positioning in the frontal plane during the exercise.\(^1,13,14\) Other weight bearing exercises include double-leg and single-leg squats, leg press, forward and lateral lunges, and step-ups. Performing these exercises with proper biomechanics may improve hip muscle recruitment and force production of the extensors and abductors during functional and sports specific movements.\(^7\) Weight bearing exercises are generally favored because they better replicate functional and athletic movements as compared to non weight bearing exercises.\(^7,15,16\)

Hip abductor strengthening has been described as an important intervention in individuals with knee pain.\(^1,13\) Several authors describe the activation of gluteus maximus and gluteus minimus during specific exercises\(^1,13,14,17\) as well as gluteus maximus and gluteus medius activation during stepping, squatting activities, and lunges.\(^13,14\) Presently, the authors of this paper are not aware of research that has identified how the activity of these muscles is altered when a frontal plane load is applied to the knee during stepping and squatting exercises. Therefore, the primary purpose of this study was to determine which of three exercises (double-leg squat, single-leg squat, or front step-up) was most effective in facilitating hip muscle activation while maintaining a more neutral varus/valgus knee frontal plane alignment in healthy female subjects. A secondary objective was to determine how added medial pull on the knee during these exercises altered the magnitude of gluteus maximus and gluteus medius activation while enabling the maintenance of neutral varus/valgus knee alignment during the task.

METHODS
A repeated measures study design was used. The independent variables included the exercise (double-leg squat, single-leg squat, or front step-up) and the medial or unloaded condition. The dependent
variables were the integrated percentage of the maximal voluntary isometric contraction (% MVIC*s), peak %MVIC, and peak knee abduction angle during exercise.

Eighteen healthy females between the ages 18-26 years (average age 22.3 years, SD 2.3) with an average height 166.82 cm (SD 9.2) and average weight 61.1 kg (SD 7.1) were recruited to participate in this study. Inclusion criteria were that participants had no current injuries or pain in their lower extremities. Injury was defined as an event that occurred during athletic participation that required treatment or required refraining from participation for at least one day. Participants also reported no history of surgical intervention of the spine or lower extremities that may have influenced the data. The dominant leg was determined by asking the subject which leg she would use to kick a soccer ball. Each subject's height, weight, leg length were recorded. Before participating, subjects were informed of possible risks and signed an informed consent form approved by the University institutional review board.

Eight Eagle high speed video cameras (Motion Analysis Corp., Santa Rosa California) were positioned around the laboratory such that at least two cameras could identify and track each retroreflective marker placed on the subject. Three markers placed on rigid shells were strapped to the dominant thigh and shank (Figure 1). A static neutral standing trial was used to identify joint centers of the knee and ankle by anatomical markers on the medial and lateral condyles and malleoli. Ankle and knee centers were determined by taking half the distance between the medial and lateral markers. The hip joint center was determined based on markers placed on the greater trochanters of the femur, and 25% of the horizontal distance from the tested leg was used to calculate this location. All video from the cameras and analog data from the force platform measures were collected (120 Hz for video and 1200 Hz for analog) using Eva 6.4 (Motion Analysis Corp.) and stored on a personal computer. All marker data were identified and exported to the Motion Monitor Software (Version 7.0, Innovative Sports Training, Chicago, IL) to create the rigid bodies of the thigh and shank. All data were smoothed using a low pass Butterworth recursive (fourth order) at eight Hz based on the frequency content of the data. Knee abduction angles were determined from the thigh and shank coordinate data.

Surface electromyography (EMG) recordings were collected from two muscles of the dominant leg of each subject, the gluteus medius and gluteus maximus, using the landmarks described by Cram et al. Before placement of the surface electrodes on the subject, the skin was prepared by abrading the skin with sandpaper and cleansing the skin with alcohol to reduce skin impedance. EMG data were captured at 960 Hz using the Data Pac 2K2 acquisition software (Run Technologies, Version 3, Mission Viejo, CA, USA). Delsys DE2.1 surface electrodes and a Bagnoli 8 amplifier (Delsys, Inc, Boston, MA, USA) interfaced with a second PC. The system bandwidth...
was 20-450 Hz with a gain of 1000. Electrode placements were based on those used by Cram et al.\textsuperscript{19} Data were high pass filtered using a 4th order Butterworth recursive filter at 30 Hz, rectified and low pass filtered with a 4th order Butterworth recursive filter at 6 Hz.\textsuperscript{20} EMG data were collected using DataPac 2k2 (Run Technologies, Mission Viejo, CA) and integrated over the duration of each exercise trial using a customized Matlab program (The Mathworks, Inc., Natick, Massachusetts). Integrating the individual EMG signals serves to determine the net activation required by the muscles involved in the task by determining the area under the processed curves. The data were normalized to the % MVIC to allow for comparison between subjects.

During these exercises, EMG data was synchronized with video data by using a force platform interfaced with both the EMG and the motion analysis system on each computer. The subject was instructed to perform each exercise stepping onto and off of the force platform. Data based on a portion of the participant’s body weight based on the vertical ground reaction force (increase of greater than 5%) was used to determine when movement began on both recording systems. The force platform loading and unloading events served as a point of synchronization between systems.

After the surface electrodes were attached to the subject, the subject performed three maximal voluntary isometric contractions (MVIC) for each muscle.\textsuperscript{21} An investigator applied manual resistance for the MVIC which were held for five seconds. To obtain the MVIC for the gluteus maximus, the subject was placed in a prone position with the knee flexed to approximately 90 degrees and asked to maximally extend the hip. To obtain the MVIC for the gluteus medius, the subject was placed in a side-lying position with the hip in a neutral position and asked to maximally abduct the hip while maintaining the lower extremity in the frontal plane. All subsequent EMG recordings were normalized to the MVIC and were reported as a percent of MVIC.

After the MVIC data were collected, the retroreflective markers were placed on the subject. After collection of the static, anatomical neutral motion capture file to identify the location of the joint centers for the ankle and hip, the investigator then provided instruction for how each exercise would be performed. The subject performed the following six exercise activities in a randomized order: double-leg squat (Figure 2), double-leg squat with lateral resistance via a green resistance band applied at the knee (Theraband, Hygenic Corp, Akron, Ohio) tied in a 30 cm loop and applied around both LE’s (Figure 3), front step-up (Figure 4), front step-up with an applied resistance via a cable column pulling horizontally in a medial direction (Figure 5), single-leg squat (Figure 6), and single-leg squat with resistance via a cable column pulling horizontally in a medial direction (Figure 7). The subject was allowed to practice each exercise several times before data were collected. Five repetitions of each exercise were performed and used for simultaneous EMG and motion analysis data collection. Between each repetition was a 10-15 second rest interval and between each exercise was a 45-60 second rest interval. The level of applied resistance for the

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Participant performing a double-leg squat exercise.}
\end{figure}
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front step-up and single-leg squat was set to 15% of the subject’s body weight. This weight was established after a pilot investigation of 5 subjects not involved in this study. It was determined that this weight would provide ample force without disturbing the subjects ability to perform the desired maneuver. The cable with the weight stack resistance was created specifically for this investigation such that the pull of the cable could be raised or lowered such that the line of pull was perpendicular to the limb. Each exercise was performed to the beat of a metronome set at 40 beats per minute where beat 1 initiated the repetition, beat two marked the mid-point between the concentric and eccentric phases, and beat three marked the end of the repetition. One full repetition lasted three-seconds in duration. Each subject was allowed to use a vertical pole to maintain balance on the side being tested. The subjects were monitored by visually observing for excessive trunk lean toward the pole to ensure that significant weightbearing did not occur through the upper extremity holding onto the pole. Other authors have utilized a similar protocol during their data collection to maintain balance.13 The subjects were encouraged to maintain their knee over their ankle during each exercise. They were also given verbal cues to maintain an upright and vertical position of the head and trunk. The average normalized integrated EMG, peak EMG activity and peak knee valgus angle from five trials were used for statistical analysis.

**STATISTICAL ANALYSIS**

A two way analysis of variance with repeated measures using two within subject factors (exercise: double-leg squat, single-leg squat, front step-up; and with or without an applied load to the knee) was utilized. These were run separately on the average normalized integrated gluteus maximus and gluteus

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**Figure 3.** Participant performing a double-leg squat exercise with medial knee resistance via a resistance band. Arrow depicts direction of pull on the knee.

**Figure 4.** Participant performing a front step-up exercise.
medius activity, average peak normalized gluteus maximus and gluteus medius activity and the peak knee valgus angle. Alpha for all statistical tests was chosen, apriori to be 0.05. Post-hoc comparisons were performed as warranted by running pairwise t-tests using the Bonferoni procedure.

**RESULTS**

Muscle activation of gluteus maximus and gluteus medius were monitored during three exercises: double-leg squat, single-leg squat, and step-up for two conditions (with and without an applied load to the knee). Table 1 depicts the integrated gluteus maximus activation during these exercises with and without an applied load to the knee. There was a statistically significant difference in muscle activation between the three exercises (double-leg squat, single-leg squat, and step-up) for gluteus maximus (p=0.000). The application of an applied load did not change the amount of integrated activation across all exercises for the gluteus maximus (p=0.550). There was an exercise by applied load interaction for the gluteus maximus (p=0.017) indicating that the presence of the load did influence the integrated muscle activation among the three exercises. When an applied load was added to the double-leg squat, gluteus maximus activation increased by 6% MVIC*sec (p=0.019). When an applied load was added to the step-up and single-leg squat gluteus maximus activation decreased by 2% MVIC*sec and 7.4% MVIC*sec, respectively. However, this change in muscle activation was not large enough to be considered significant for either the step-up (p=0.598) or the single-leg squat (p=0.053).

The integrated gluteus medius activation during the exercises with and without an applied load to the
The knee is depicted in Table 2. There was also a statistically significant difference in normalized integrated muscle activation across the three exercises (double-leg squat, single-leg squat, and step-up) for gluteus medius (p = 0.000) as well as a change in the normalized integrated activation across all exercises with the application of a valgus load (p = 0.019). There was an exercise by applied load interaction indicating that the presence of load did influence normalized integrated muscle activation among the three exercises for gluteus medius (p = 0.001). When an applied load was added to the double-leg squat, the normalized integrated gluteus medius activation increased non-significantly, or by only 2.9% MVIC*sec (p = 0.112). The application of an applied load to the step-up decreased the amount of integrated gluteus medius activation non-significantly by 3.0% MVIC*sec (p = 0.223). When an applied load was added to the single-leg squat, there was a significant 11.9% MVIC*sec decrease in the integrated gluteus medius activation (p = 0.002).

Table 2. Two-way analysis of variance results and means (SD) for integrated gluteus medius electromyography (EMG) during exercises with and without an applied load to the knee.

<table>
<thead>
<tr>
<th>Exercise Type</th>
<th>No Applied Load Mean (SD)</th>
<th>Applied Knee Load Mean (SD)</th>
<th>Exercise Main Effect Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double Leg Squat</td>
<td>20.8 (14.7)</td>
<td>23.7 (16.3)</td>
<td>22.5 (15.5)</td>
</tr>
<tr>
<td>Step-Up</td>
<td>48.2 (20.4)</td>
<td>45.2 (21.7)</td>
<td>46.7 (21.1)</td>
</tr>
<tr>
<td>Single Leg Squat</td>
<td>65.6 (23.8)</td>
<td>53.7 (27.6)</td>
<td>59.7 (25.7)</td>
</tr>
<tr>
<td>Load Main Effect Mean (SD)</td>
<td>44.9 (19.6)</td>
<td>40.9 (21.9)</td>
<td></td>
</tr>
</tbody>
</table>

*Note: Data are expressed as a percentage of maximum voluntary isometric contraction (% MVIC * sec)

Table 3 depicts the peak gluteus maximus activity during the exercises with and without an applied load. When examining average peak normalized muscle activation, there was a significant difference in activation across the three exercises for gluteus maximus (p = 0.000). There was also a change in the average peak normalized gluteus maximus activation across all exercises with the application of the load (p = 0.042). Follow up pairwise comparisons tests showed there was no difference between the means for any of the three exercises with or without load (p > 0.05). There was no exercise by load interaction for the average peak normalized gluteus maximus activation (p > 0.05).
The average normalized peak gluteus medius activation during the exercises with and without a load is provided in Table 4. Examining average peak normalized muscle activation, there was a significant difference across the three exercises for gluteus medius (p = 0.000). There was also exercise by applied load interaction in the average peak normalized gluteus maximus activation (p = 0.019) indicating that the load influenced the peak activation among the three exercises. There was an exercise by load interaction for average peak gluteus medius activation (p = 0.026). With the addition of the load to the single-leg squat, there was a 7.5% MVIC decrease in peak activation for the gluteus medius (p = 0.003). There was no significant change in the average normalized peak activation of the gluteus medius during the front step-up (p = 0.924) or double-leg squat (p = 0.560) with the addition of a load.

Table 5 depicts the significant difference in peak knee abduction angles between the three exercises (p = 0.011) which occurred between conditions with or without a medial pull applied to the knee (p = 0.000). There was an interaction between the exercise and applied load on the amount of knee abduction (p = 0.016). When the load was added, there was an increased knee abduction angle demonstrated across all three exercises. With the load applied, the peak knee abduction angle increased by 1.9º during the double-leg squat (p = 0.013), 6º during the step-up (p = 0.000), and 3.9º during the single-leg squat (p = 0.011), each of which was a significant increase.

**DISCUSSION**

The researchers examined the average normalized peak and integrated EMG activation of the gluteus maximus and gluteus medius during three different LE exercises (double-leg squat, single-leg squat, and step-up) under two separate conditions (with and without a load pulling the knee in a medial direction). The single-leg squat had the highest integrated activation for both gluteus maximus (47.4% MVIC*s) and gluteus medius (65.6 %MVIC*s), regardless of whether a load was applied. Therefore, the results of this study suggest that the single-leg squat may be the most effective of the three exercises for activating gluteus maximus and gluteus medius.

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**Table 3.** Two-way analysis of variance results and means (SD) for peak gluteus maximus electromyography (EMG) during three different exercises with and without an applied load to the knee.

<table>
<thead>
<tr>
<th>Exercise Type</th>
<th>No Applied Load Mean (SD)</th>
<th>Applied Knee Load Mean (SD)</th>
<th>Exercise Main Effect Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double Leg Squat</td>
<td>22.0 (16.6)</td>
<td>25.8 (18.7)</td>
<td>23.9 (17.7)</td>
</tr>
<tr>
<td>Step-Up</td>
<td>33.5 (13.4)</td>
<td>37.8 (11.4)</td>
<td>35.7 (12.4)</td>
</tr>
<tr>
<td>Single Leg Squat</td>
<td>40.5 (16.8)</td>
<td>36.7 (11.2)</td>
<td>38.6 (14.0)</td>
</tr>
<tr>
<td>Load Main Effect Mean (SD)</td>
<td>32.0 (15.6)</td>
<td>33.4 (13.8)</td>
<td></td>
</tr>
</tbody>
</table>

*Note: Data are expressed as a percentage of maximum voluntary isometric contraction (% MVIC).

**Table 4.** Two-way analysis of variance results and means (SD) for peak gluteus medius electromyography (EMG) during exercises with and without an applied load to the knee.

<table>
<thead>
<tr>
<th>Exercise Type</th>
<th>No Applied Load Mean (SD)</th>
<th>Applied Knee Load Mean (SD)</th>
<th>Exercise Main Effect Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double Leg Squat</td>
<td>17.6 (10.4)</td>
<td>18.7 (11.1)</td>
<td>18.2 (10.8)</td>
</tr>
<tr>
<td>Step-Up</td>
<td>43.5 (14.4)</td>
<td>43.8 (20.1)</td>
<td>43.7 (17.3)</td>
</tr>
<tr>
<td>Single Leg Squat</td>
<td>47.5 (13.2)</td>
<td>40.0 (13.8)</td>
<td>43.8 (13.5)</td>
</tr>
<tr>
<td>Load Main Effect Mean (SD)</td>
<td>36.2 (12.7)</td>
<td>34.2 (15.0)</td>
<td></td>
</tr>
</tbody>
</table>

*Note: Data are expressed as a percentage of maximum voluntary isometric contraction (% MVIC).

**Table 5.** Two-way analysis of variance results and means (SD) for peak knee abduction angles (degrees) during exercises with and without an applied load to the knee.

<table>
<thead>
<tr>
<th>Exercise Type</th>
<th>No Applied Load Mean (SD)</th>
<th>Applied Knee Load Mean (SD)</th>
<th>Exercise Main Effect Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double Leg Squat</td>
<td>-4.1 (3.5)</td>
<td>-6.0 (2.6)</td>
<td>-5.1 (3.1)</td>
</tr>
<tr>
<td>Step-Up</td>
<td>-4.2 (3.8)</td>
<td>-10.2 (2.9)</td>
<td>-7.2 (3.4)</td>
</tr>
<tr>
<td>Single Leg Squat</td>
<td>-5.6 (4.0)</td>
<td>-9.2 (3.5)</td>
<td>-7.4 (3.8)</td>
</tr>
<tr>
<td>Load Main Effect Mean (SD)</td>
<td>-4.6 (3.8)</td>
<td>-8.5 (3.0)</td>
<td></td>
</tr>
</tbody>
</table>

*Note: Data are expressed in degrees. Negative numbers depict knee abduction or valgus angles and positive numbers represent knee adduction or varus angles.
Normalized average peak activation was also assessed to determine which of the three exercises would be most beneficial for strengthening gluteus maximus and gluteus medius. Ekstrom et al. reported that a peak activation of 45%-50% of MVIC was required to strengthen trunk, hip, and thigh musculature. Andersen et al. indicated that an adaptive threshold of 40% to 60% of maximal effort is needed for strengthening the lower extremity musculature during therapeutic exercise. When viewed in the context of the current investigation, these suggestions indicate that the single-leg squat without the medial pull may be the only LE exercise to achieve this activation percentage in gluteus maximus (40.5% MVIC). For the gluteus medius, the step-up (43.5% MVIC), step-up with applied load (43.8% MVIC), single-leg squat (47.5% MVIC), and the single-leg squat with applied load (40.0% MVIC) all reached this adaptive threshold for muscle strengthening. Overall, the single-leg squat reached the adaptive threshold for strengthening in both muscles, with the highest normalized activation percentage of all the exercises tested.

Although the front step-up exercise for the gluteus maximus and the double-leg squat for both gluteus maximus and medius did not reach the adaptive threshold for strengthening, they may still be considered for use in muscle endurance training. Souza and Powers reported that women with patellofemoral pain (PFP) had significantly greater hip internal rotation during running (p < 0.001), decreased hip muscle strength in eight of ten hip strength measurements (p < 0.05), and decreased hip extension isotonic endurance (p <0.05) when compared to a control group. Of the hip muscle performance tests, isotonic hip extension endurance was the best predictor of average hip internal rotation motion during running. These findings may support the use of muscular endurance training in rehabilitation of those with PFP. As the gluteus maximus is the primary extensor and external rotator of the hip, poor gluteus maximus endurance may result in decreased ability to control transverse plane motions of the lower extremity during sustained weight bearing activities. Therefore, exercises that target the gluteus maximus may be useful in endurance training protocols for the hip in rehabilitation and prevention of injury.

A secondary goal of this study was to determine if an added load increased the activation of the tested hip muscles. Although the double-leg squat achieved the lowest integrated activation, using a resistance band to add apply a medial pull to the knees increased integrated muscle activation by 6% MVIC*sec. The valgus load increased knee abduction by 1.9 degrees due to the applied medial pull, which the authors suspect is not large enough to be deleterious for those who perform this exercise. This medial pull was greater than the standing reference angle based on the static neutral trial obtained during testing prior to the dynamic movement trials. Certainly, if the addition of a medial pull during a double-leg squat is provocative of pain, professionals should consider removing or reducing this load. Although the double-leg squat resulted in lower muscle activation than single-leg exercises, the addition of load while completing squats may be indicated in a population with reduced strength of the hip extensors and abductors.

While the addition of an applied load increased the amount of integrated muscle activation during the double-leg squat, this was not the case in the single leg stance exercises. Both the single-leg squat and the step-up exercise showed a decreased integrated muscle activation and an increased knee abduction angle when the load was applied. In the single-leg squat, integrated muscle activation of the gluteus medius decreased by 11.9% MVIC*sec indicating that adding the load from the cable column did not provide cueing to prompt greater integrated muscle activation in order to resist knee abduction. This may indicate that the subjects compensated for the applied load with means other than increasing their integrated gluteus maximus and gluteus medius activation such as trunk movement and weight shifting over their stance leg. The results during single leg squat activities with added load may also indicate that the 15% of the participant’s body weight applied by the cable column may have been too large to resist during the single-leg squat and front step-up. It is possible that a smaller applied load may be sufficient for eliciting enhanced muscle activation while maintaining appropriate knee abduction during the exercise.

The data from this investigation may also be used to identify those exercises that activate the gluteus maximus and gluteus medius and promote knee
abduction alignment. Greater muscle activation at the hip may help in achieving safer knee mechanics during functional and athletic movements. Once exercises that are effective in increasing muscle activation and strength at the hip are identified, they may be employed to improve training programs for reducing knee injury risks caused by athletic movements that involve large amounts of deceleration such as landing, and cutting.7,25,26

Research suggests that the combination of hip adduction and internal rotation25 along with inadequate or abnormal neuromuscular control of lower extremity biomechanics are factors related to the ACL-injury mechanism.2,8,25-28 Other studies have also established that increased knee abduction, caused by hip adduction and internal rotation, increases ACL strain.29-33 Weakness in the gluteus maximus and gluteus medius may predispose an individual to increased knee valgus since the gluteus maximus functions as a powerful hip extensor, external rotator and abductor.34 The gluteus medius also functions as a hip abductor and external rotator.2

Other knee overuse pathologies may also be related to decreased hip abductor strength. Fredericson et al2 reported that runners with iliotibial band syndrome (ITBS) exhibited weaker hip abductor strength on their affected side compared to their unaffected side. They reported that improving hip abductor strength resulted in a decrease in ITBS symptoms. Females with PFP have also been reported to have weaker hip abductors, extensors, and external rotators as compared to age-matched controls.34,35 Strengthening these muscles resulted in a significant improvement of PFP, lower extremity kinematics, and a return to activity.

As the gluteus maximus and gluteus medius are both involved in frontal plane knee alignment and have been shown to be connected to ACL injuries, ITBS, and PFP, strengthening of these muscles becomes a primary goal in both the prevention and rehabilitation of these injuries. The results of the current study indicate that the single leg squat may be the most effective exercise, of those tested in this investigation, for activating the hip abductors and extensors.

There are several limitations present in this study. Researchers chose to utilize surface EMG rather than the use of fine wire techniques to quantify the activation of the tested muscles. Surface EMG was chosen since it may be able to better reflect the gross muscle activation of these muscles for a study of their function during exercise.36 The use of young, healthy volunteers as subjects limits the ability to apply these results to patients recovering from injury; however, using healthy subjects supports the use of these exercises for the prevention of ACL injuries. While subjects were allowed to use a pole for balance during single leg stance activities, this may not have been sufficient to prevent changes in trunk position, therefore allowing participants to lean or shift their weight within their base of support. The pole was used on the side of weight bearing LE in this investigation. This use could have artificially changed the activation state of the hip musculature due to the additional stabilizing moment added to the hip.37 Also, trunk lean and pelvis positioning could have influenced the magnitude of muscle activation. Bolga and Uhl1 described how trunk lean and resultant pelvis positioning toward the weight bearing side could influence the external moment due to the upper body reducing the demands of the hip abductors during exercise. Better experimental control for trunk and pelvis position may be warranted in future investigations on this topic. This control, however, limits the applicability of the results in a clinical setting as there would likely be less control over trunk position.

Another limitation was the use of a metronome. Using a metronome requires the subjects to move at a speed that may not be typical during daily activities. At a non-controlled speed, the frontal plane angle and gluteus maximus and medius activation may have been different, which may limit the application to a clinical setting.

Further research is needed to validate these findings and to analyze the effect of other strengthening exercises in activating the gluteus maximus and gluteus medius used in exercise programs and clinical practice. Research in the use of lower resistance loads applied at the knee may also be beneficial to determine if lower loads result in higher hip muscle activation levels with less trunk compensation. An alternative method may be to add a load to the contralateral side to increase muscle activation in the
weight bearing leg. This approach was demonstrated by Neumann et al. who reported an increase in EMG activation of the hip abductors during the stance phase of gait when carrying a load in the contralateral hand.

The results of the current study demonstrate that the use of exercises with applied load to the knee as supplied in this study may not increase the integrated or peak muscle activation of the gluteus maximus and gluteus medius during single-leg squat and step-up. However, the double-leg squat exercise with an applied load provided by a resistance band may be more beneficial than the same exercise performed without the band. The single leg squat achieved the highest integrated and peak activation of the gluteus maximus and gluteus medius of the three exercises examined.

ACKNOWLEDGEMENTS
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REFERENCES


ABSTRACT

Introduction: Understanding the relationships between performance tests and sport activity is important to the rehabilitation specialist. The purpose of this study was two-fold: 1) To identify if relationships exist between tests of upper body strength and power (Single Arm Seated Shot Put, Timed Push-Up, Timed Modified Pull-Up, and The Davies Closed Kinetic Chain Upper Extremity Stability Test, and the softball throw for distance), 2) To determine which variable or group of variables best predicts the performance of a sport specific task (the softball throw for distance).

Methods: One hundred eighty subjects (111 females and 69 males, aged 18-45 years) performed the 5 upper extremity tests. The Pearson product moment correlation and a stepwise regression were used to determine whether relationships existed between performance on the tests and which upper extremity test result best explained the performance on the softball throw for distance.

Results: There were significant correlations (r = .33 to r = .70, p = 0.001) between performance on all of the tests. The modified pull-up test was the best predictor of the performance on the softball throw for distance (r² = 48.7), explaining 48.7% of variation in performance. When weight, height, and age were added to the regression equation the r² values increased to 64.5, 66.2, and 67.5 respectively.

Conclusion: The results of this study indicate that several upper extremity tests demonstrate significant relationships with one another and with the softball throw for distance. The modified pull up test was the best predictor of performance on the softball throw for distance.

Key Words: functional testing, upper body strength, upper body power

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INTRODUCTION
Physical therapists and strength and conditioning professionals attempt to develop optimal training programs for overhead throwing athletes to prevent injury, enhance performance, and safely progress a patient through rehabilitation. Determining specific upper extremity (UE) strength and power activities that best relate to throwing, and furthermore predict throwing performance, would provide clinically relevant information to the health care professional.

Several authors document the extreme biomechanical forces that occur at the shoulder and elbow during a pitching motion.1-4 Werner et al4,5 studied the distraction forces present at the glenohumeral joint during an overhead throwing action. The distraction force ranged from 81% to 108% of a subject’s body weight for collegiate and professional baseball pitchers. Throwing injuries are common to sports like baseball and softball. Powell and Barber-Foss6 reported a 19.7% shoulder/arm injury rate for high school baseball players and 16.3% shoulder/arm injuries in high school female softball players in 100 high schools throughout the country during the 1995-1997 seasons. Dick et al7 reported 23.4% and 16% shoulder injury rates in collegiate baseball games and practice respectively from 1988-2004. In Major League Baseball, Conte8 reported an injury rate of 27.8% for the shoulder and that pitching related shoulder injuries accounted for 56.9% of total disabled-list days. These data suggest that preventative strategies and exercise programs may need to be further developed to possibly prevent these types of UE injuries.

Specific exercises can elicit increased muscular activity of targeted muscles for use in rehab and injury prevention. Several authors have used electromyographic (EMG) studies to examine several exercises and determine which ones optimally activate the rotator cuff and scapulothoracic musculature.9,10 Moseley et al9 and Townsend et al10 have described exercises such as the push up with a plus, press up, scaption, shoulder flexion, rowing, prone external rotation, and horizontal abduction, to be effective in eliciting increased EMG activity in the muscles of the shoulder girdle. EMG studies like these have led to the development of rehabilitation protocols for shoulder girdle injuries. A multi-phase rehabilitation regimen has been described for the conservative treatment of shoulder injuries for throwing athletes.11 Stodden et al12 recommended throwers should strengthen shoulder and elbow muscles that resist distraction as well as improve trunk strength and flexibility to maximize throwing velocity and help prevent injury. A clinical test that can predict throwing distance with an overhead throwing motion could be a valuable addition to a screening, training and rehabilitation program for baseball and softball athletes. Measures of muscle performance may detect impairment before a decline in functional performance exists. When assessing the ability of an athlete to return to overhead throwing, following an injury, several non-specific (non-throwing) strength/power tests may assist in determining the level of activity at which an athlete can perform or to which they could be safely returned. Relationships must exist between the outcomes of muscle performance tests and overhead throwing if they are to predict a safe progression back to this functional activity. The objectives of the present study are to determine if relationships exist between upper body tests of strength and power and the softball throw and to study their predictive ability for a softball throw for distance.

METHODS
Participants
One hundred and eighty healthy, recreationally active adults, 111 females and 69 males, between the ages of 18 and 45 years old volunteered to participate in this study. Subjects were tested at one of 3 sites. The Institutional Review Boards of each of the sites approved the study. Informed consent was obtained from each subject prior to testing, and a health history form was completed. No participants were currently involved in competitive throwing related activities and anyone with a history of upper extremity injury or surgery was excluded from participation.

Procedures
After obtaining consent subjects were brought to a climate controlled indoor testing area for completion of all tests with the exception of the softball throw which was performed outdoors in an open field. Subjects wore loose, comfortable clothing which would not restrict physical movements.
Five activities requiring upper body strength and power were performed by all subjects, in random order, including:

1. Single Arm Seated Shot Put with a 2.72 kg medicine ball, performed by both the right and left upper extremities.

2. Timed Push-Up for 3 sets of 15 seconds.

3. Timed Modified Pull-Up for 3 sets of 15 seconds on a modified Smith Press machine or similar apparatus.

4. The Davies Closed Kinetic Chain Upper Extremity Stability Test for 3 sets of 15 seconds.

5. The Underkofler Softball Throw for distance using the one-step-throw approach.

All participants watched a short video demonstrating the technique for each of the 5 tests. After watching the video, participants began a five-minute warm-up of self-selected moderate intensity, on a seated Upper Body Ergometer (Biodex Inc. Shirley, NY). This was followed by three minutes of upper body stretching including, a corner stretch for the anterior shoulder girdle, a shoulder horizontal adduction stretch for the posterior shoulder girdle, and a trunk side-bending overhead reach for the trunk and inferior shoulder girdle. Each subject was given a random ordered data sheet to take to each testing station for recording results of the 3 maximal effort bouts for each test. The single arm seated shot put test involved testing each UE, therefore, the order of testing of the dominant and non-dominant UE’s was randomized on each of the data sheets.

The Single Arm Seated Shot Put Test

The one arm seated shot put was performed with the subject seated in a standard 45.72 cm chair without armrests, from which the subjects “put” a 2.72 kg medicine ball (Figure 1). The front legs of the chair were placed on a line made by the tester. The subjects were seated in the chair with their feet and lower legs placed on another 45.72 cm chair, positioned just in front of their chair. The non-throwing arm was placed across the chest and a strap placed diagonally around the upper body to secure the subject to the chair. This position minimized the use of the legs and trunk during the seated shot put.

Participants were instructed to “put” the medicine ball using an arm motion resembling that used by shot put athletes during this particular track and field event. Specific instruction not to “throw” the medicine ball in an overhead baseball type fashion was given. The initial test arm was selected as documented on the randomized data sheet the participants were given prior to testing. Prior to the recorded puts, four gradient self-selected sub-maximal to maximal warm-ups of 25%, 50%, 75% and 100% effort seated one arm shot puts were performed. The participant then rested for two minutes, followed by 3 maximal effort puts. The recorder measured from the tapeline at the front of the subject’s chair to the site where the ball first struck the ground. Two minutes of recovery was given before testing the opposite arm in the same manner described above. The average distance of the 3 maximal effort puts for each arm was used for the data analysis. This test has been previously studied with test-retest reliability of ICC = 0.99 for the dominant arm and ICC = 0.97 for the non-dominant arm.¹³

The Push-up test

The push-up test was performed in either the standard position for men (on hands and toes) or in the modified position for women in which the subjects assumed the hands and knees position (Figure 2a and 2b). Participants were positioned prone with hands shoulder width apart with the trunk held in a rigid, straight position. Push-ups were performed as...
legs. Participants assumed a supine position with their heels on a bench, and using an overhand grip to clench the bar. The bar was positioned approximately 7.6 cm out of arms reach when the participant was supine on the floor. Men performed the pull-up with their legs supported at their heels. Women had their lower legs supported just below the knees. When performing the modified pull-up participants started by hanging from the bar with arms fully extended and pulled up high enough so the upper arms were parallel to the floor. The participants then lowered themselves back to the elbows fully extended position (Figure 3). The participants were instructed to continuously keep a straight trunk posture and to limit trunk and head motion. A warm-up trial was completed prior to the 3 maximal effort trials. Each participant completed as many pull-ups as possible in 15 seconds during the 3 maximal trials. A 45 second rest period was given between each maximal test bout. The average number of modified pull-ups completed for the 3 maximal effort 15 second bouts was recorded and used for data analysis. This test has been previously studied and a test-retest reliability of ICC = 0.99 was reported.

Davies Closed Kinetic Chain Upper Extremity Stability Test

For the Davies Closed Kinetic Chain (CKC) Upper Extremity Stability Test the experimenter placed two parallel strips of tape on the floor three feet apart (Figure 4). The participant was instructed to assume the push-up position and move their hands alter-
DATA ANALYSIS

All data were entered into SPSS 12.0 for statistical analysis. Descriptive statistics, including age, height (cm), weight (kg) and mean scores for each of the 5 tests were calculated for all subjects. A two-tailed Pearson Correlation analysis was performed to determine if relationships existed between the four tests (single arm seated shot put, timed push up, timed modified pull up, Davies CKC test) and the softball throw. A stepwise multiple regression analysis was used to determine which of the 4-tests could best predict performance on the softball throw for distance. Additionally, the variables of height, weight and age were added into the regression analysis. The level of significance for the statistical tests was set at p = 0.05.

RESULTS

All 180 subjects successfully completed the testing procedures. Descriptive variables including both the mean and standard deviations of subject characteristics and the test scores are presented in Table 1. Pearson product correlations between all functional performance variables for participants are shown in Table 2. The modified pull-up test had the strongest correlation with the softball throw for distance (r = 0.70), followed closely by the push up test (r = 0.63). Both the modified pull up and the push up test were statistically significantly correlated (p = .001) with the softball throw.

The regression analysis (Table 3) indicated the modified pull-up test to be the best predictor of the softball throw.

| Table 1. Descriptive statistics for the entire group n = 180 |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| Variable                        | Minimum         | Maximum         | Mean            | Std. Deviation  |
| Age                             | 18              | 45              | 24.29           | 5.329           |
| Height (cm)                     | 144.8           | 200.7           | 171.98          | 10.64           |
| Weight (kg)                     | 45.4            | 120.2           | 70.49           | 14.27           |
| ST score (meters)               | 6.8             | 65.7            | 29.4            | 14.3            |
| DCKC score                      | 4.7             | 38.0            | 20.74           | 5.650           |
| PU score                        | 4.3             | 25.3            | 15.13           | 4.536           |
| MPU score                       | 0               | 21.7            | 7.53            | 4.972           |
| SSP dominant score (cm)         | 88.9            | 743.5           | 234.95          | 129.82          |
| SSP non-dominant score (cm)     | 31.24           | 602.74          | 212.37          | 116.57          |

ST = softball throw, DCKC = Davies closed kinetic chain test, PU = push-up, MPU = modified pull-up, SSP = seated shot put.
The results of this investigation suggest that the best predictors of the softball throw for distance are the modified pull-up test as well as weight, height, and age. The modified pull up and push up tests were strongly correlated with throwing distance, and weak correlations were found between the one arm shot put and Davies CKC score and throwing distance. The correlation between the timed modified pull-up and push-up with the softball throw may indicate these strength/power maneuvers may have relevance as assessment tools for the throwing population.

Several authors have performed studies that suggest the beneficial effects of resistive exercise and upper body plyometrics on velocity of throwing in both males and females. Fleisig et al² stated that at ball release, significant energy and momentum is transferred to the ball and throwing arm. After ball release, a kinetic chain is used to decelerate the rapidly moving arm with the entire body, allowing proper dissipation of the forces from the arm to the trunk and lower extremities.² Shoulder and elbow muscles produce

<table>
<thead>
<tr>
<th>Table 2. Correlational Matrix for entire group n=180</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Softball Throw Score</strong></td>
</tr>
<tr>
<td>----------------------------</td>
</tr>
<tr>
<td><strong>Pearson Correlation</strong></td>
</tr>
<tr>
<td><strong>Sig. (2-tailed)</strong></td>
</tr>
</tbody>
</table>

| **Davies CKC Score**      | **Pearson Correlation** | 0.33 | 1.00 | 0.54 | 0.59 | 0.63 | 0.66 |
| **Sig. (2-tailed)**       |                      | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |

| **Push-up Score**         | **Pearson Correlation** | 0.63 | 0.54 | 1.00 | 0.76 | 0.44 | 0.45 |
| **Sig. (2-tailed)**       |                      | 0.01 | 0.01 | --   | 0.01 | 0.01 | 0.01 |

| **Modified Pull-up Score**| **Pearson Correlation** | 0.70 | 0.59 | 0.76 | 1.00 | 0.56 | 0.56 |
| **Sig. (2-tailed)**       |                      | 0.01 | 0.01 | 0.01 | --   | 0.01 | 0.01 |

| **Shot Put Dominant Score**| **Pearson Correlation** | 0.46 | 0.63 | 0.44 | 0.56 | 1.00 | 0.98 |
| **Sig. (2-tailed)**       |                      | 0.01 | 0.01 | 0.01 | 0.01 | --   | 0.01 |

| **Shot Put Non-dominant Score**| **Pearson Correlation** | 0.45 | 0.66 | 0.45 | 0.56 | 0.98 | 1.00 |
| **Sig. (2-tailed)**       |                      | 0.01 | 0.01 | 0.01 | 0.01 | --   | 0.01 |

Note: All correlations are significant to the p<.001 level (2-tailed).

<table>
<thead>
<tr>
<th>Table 3. Regression model summary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model</strong></td>
</tr>
<tr>
<td>Modified Pull-up</td>
</tr>
<tr>
<td>Modified Pull-up, Weight</td>
</tr>
<tr>
<td>Modified Pull-up, Weight, Height</td>
</tr>
<tr>
<td>Modified Pull-up, Weight, Height, Age</td>
</tr>
</tbody>
</table>

The results of this investigation suggest that the best predictors of the softball throw for distance are the modified pull-up test as well as weight, height, and age. The modified pull up and push up tests were strongly correlated with throwing distance, and weak correlations were found between the one arm shot put and Davies CKC score and throwing distance. The correlation between the timed modified pull-up and push-up with the softball throw may indicate these strength/power maneuvers may have relevance as assessment tools for the throwing population.

Several authors have performed studies that suggest the beneficial effects of resistive exercise and upper body plyometrics on velocity of throwing in both males and females. Fleisig et al² stated that at ball release, significant energy and momentum is transferred to the ball and throwing arm. After ball release, a kinetic chain is used to decelerate the rapidly moving arm with the entire body, allowing proper dissipation of the forces from the arm to the trunk and lower extremities.² Shoulder and elbow muscles produce
large compressive forces to resist joint distraction. Considering these potentially destructive forces to the shoulder joint, it makes sense that decreasing the magnitude of shoulder distraction would reduce the risk of injury to this joint. The modified pull up test examined in this study may be a measure of the muscles used to counteract the forces of distraction by enhancing the upper body musculature that could be used to compress the shoulder joint and eccentrically decelerate the throwing motion.

The shoulder musculature involved with the modified pull up are considered stabilizers and decelerators, that serve to resist distraction forces about the shoulder girdle during throwing which may explain the correlation with throwing distance identified in this investigation. This is consistent with the findings of Fleisig, who found the force to decelerate the throwing arm is directly proportional to the ball velocity.

When performing the modified pull up the subject's shoulders were abducted approximately 90 degrees. This position is similar to the 95 degree shoulder abduction position at ball release and the deceleration phase reported by Fleisig. The similarity of these positions and the effect on the posterior musculature of the shoulder girdle may help explain the correlation identified in the current study. Clearly, the position of testing and the musculature used during the modified pull up is much different than actual throwing thus the strong correlation is not completely clear. Moreover, the velocity of throwing and the consideration of open kinetic chain being compared to closed kinetic chain activities make a direct link difficult to understand and describe. The authors expected a stronger correlation. Lastly, in regard to equipment, the modified pull up test can be performed in alternate, more practical ways using a metal or wooden dowel placed between 2 training tables as shown in Figure 5.

LIMITATIONS AND FUTURE RESEARCH
It should be recognized that the tests described in this study have not been tested against a formal gold standard measure of power or strength. Therefore, it is not possible to truly determine their predictive ability regarding either power or strength. None of the participants in this study were injured thus the results may not be generalized to the symptomatic population. This is a preliminary study, which could lead to further research to determine the potential validity of upper extremity functional tests with regard to injury prevention or decisions regarding return to sport or activity.

CONCLUSION
The modified pull up and push up test may be a beneficial assessment tools for throwing athletes given their correlation to throwing distance. The ability of the modified pull up to predict success with a softball throw for distance suggests its potential role in assessment of throwing athletes. The tests described in this investigation are easy to perform and require minimal space and equipment, thus could be performed in most rehabilitation settings. As part of a comprehensive rehabilitation program these performance tests may aid in determining readiness to return to a throwing sport.

REFERENCES
3. Meister K. Injuries to the shoulder in the throwing athlete. Part one: biomechanics/pathophysiology/


ABSTRACT

Purpose/Background: Patellofemoral pain syndrome (PFPS) is one of the most common and clinically challenging knee pathologies. Historically, clinicians have used a myriad of interventions, many of which have benefited some but not all patients. Suboptimal outcomes may reflect the need for an evidence-based approach for the treatment of PFPS. The authors believe that integrating clinical expertise with the most current scientific data will enhance clinical practice. The purpose of this systematic review is to provide an update on the evidence for the conservative treatment of PFPS.

Methods: The PubMed, CINAHL, and SPORTDiscus databases were searched for studies published between January 1, 2000 and December 31, 2010. Studies used were any that utilized interventions lasting a minimum of 4 weeks for subjects with PFPS. Data were examined for subject sample, intervention duration, intervention type, and pain outcomes.

Results: General quadriceps strengthening continues to reduce pain in patients with PFPS. Data are inconclusive regarding the use of patellar taping, patellar bracing, knee bracing, and foot orthosis. Although emerging data suggest the importance of hip strengthening exercise, ongoing investigations are needed to better understand its effect on PFPS.

Conclusions: Current evidence supports the continued use of quadriceps exercise for the conservative management of PFPS. However, inconsistent or limited data regarding the other interventions precluded the authors' ability to make conclusive recommendations about their use. Future investigations should focus on identifying cohorts of patients with PFPS who may benefit from the other treatment approaches included in this systematic review.

Keywords: foot orthosis, hip exercise, knee, patella bracing, patella taping, quadriceps exercise
INTRODUCTION
Patellofemoral pain syndrome (PFPS) is one of the most common knee problems experienced by active adults and adolescents. Dye has described PFPS as an orthopedic “enigma” since it is one of the most challenging pathologies to manage. Historically, clinicians have used a myriad of interventions, many of which have little, if any, supporting evidence.

Recently, much attention has focused on evidence-based practice. Sackett et al have defined evidence-based medicine as the “conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients.” They do not imply that clinicians make clinical decisions irrespective of past clinical experiences or practices. Rather, they emphasize the “integration of individual clinical expertise with the best available external clinical evidence from systematic research.”

Murray et al determined that clinicians in a sports injury clinic implemented interventions based solely on personal experience in 44% of patients treated for PFPS. Moreover, clinicians used primary research evidence in only 24% of PFPS cases. These results provided preliminary data regarding the limited use of evidence-based medicine for this patient population.

Clinicians believe that PFPS results from abnormal patella tracking that leads to excessive compressive stress to the patellar facets. Factors that may contribute to abnormal patella tracking include quadriceps weakness, quadriceps muscle imbalances, excessive knee soft tissue tightness, an increased quadriceps angle (Q-angle), hip weakness, and altered foot kinematics. Based on this clinical theory, the aim for interventions used for the treatment of PFPS is to improve patella tracking and reduce abnormal stress to patellofemoral joint structures.

Most patients with PFPS respond well to conservative interventions and evidence supports the use of exercise for the treatment of PFPS. Kettunen et al recently compared outcomes for subjects with chronic PFPS who underwent arthroscopy followed by a home exercise program to similar subjects who only participated in a home exercise program. They found that all subjects, regardless of surgical or conservative treatment, reported similar significant functional improvements.

Researchers have described many approaches for the conservative treatment of PFPS. Specific vastus medialis obliquus (VMO) and general quadriceps exercises represent the most commonly used intervention. Historically, clinicians have prescribed specific VMO exercises on the premise that a delay and/or reduction in VMO activity relative to the vastus lateralis (VL) contributes to excessive lateral patella tracking. Although evidence questions selective VMO activation during exercise, general quadriceps strengthening does benefit many patients with PFPS and is considered the “gold” standard treatment.

Other intervention strategies have incorporated patellar taping, patellar bracing, and knee bracing to further improve patella tracking. Although most subjects reported decreased pain when using these techniques, they also performed quadriceps strengthening exercises. Moreover, findings from some studies inferred limited, if any, additional benefit with patella taping or bracing over quadriceps exercise alone.

Another popular belief regarding PFPS etiology is an increased Q-angle causing the quadriceps to exert a greater lateral force vector and predispose the patella to excessive lateral tracking. This theory is not supported by the research findings, and many works have found no relationship between an increased Q-angle and PFPS. Reasons for these findings may reflect the poor reliability and validity associated with this measure. Another reason may reflect the static nature of this measure. Many patients with PFPS may demonstrate a normal Q-angle when assessed in a static manner. However, many of these patients may exhibit faulty lower extremity kinematics during dynamic activities like running, jumping, or single-leg landing that can increase the Q-angle.

To address limitations with this static measure, Powers has described use of the dynamic Q-angle since it assesses changes during dynamic, weight bearing activities. He has theorized that increased femoral adduction (relative to the pelvis) and/or femoral internal rotation (relative to the pelvis) during weight bearing activities can impart a valgus knee force and stress lateral patellofemoral joint structures. With the use of kinematic magnetic resonance
imaging (MRI), preliminary evidence\textsuperscript{26,27} has shown that subjects with PFPS demonstrated increased femoral internal rotation under a relatively stable patella during a single-leg squat. These findings provided a rationale for incorporating exercises that target the hip for patients with PFPS. Faulty foot mechanics also can affect the dynamic Q-angle. Tiberio\textsuperscript{28} theorized that excessive subtalar pronation can cause increased tibial internal rotation. Excessive tibial internal rotation would then require a greater amount of relative femoral internal rotation to extend the knee (i.e., the screw-home mechanism) during weight bearing activities. Lee and colleagues\textsuperscript{29,30} reported an association between increased lateral patellofemoral joint stress and excessive femoral internal rotation. Based on these findings, researchers have examined the use of hip strengthening\textsuperscript{10,31,32} and foot orthosis use\textsuperscript{33-35} for the treatment of PFPS.

Quadriceps strengthening exercise is the most commonly prescribed intervention. Although this approach may represent the therapist perceived “gold” standard, many patients continue to experience pain and dysfunction.\textsuperscript{11,36} This cohort of patients who may report a decrease, but not total resolution of pain following quadriceps exercise, may reflect the need to identify other evidence-supported strategies. Therefore, the purpose of this literature review is to provide an update on the evidence for the conservative treatment of PFPS. It is our intent that clinicians use information gained from this review for the development and implementation of evidence-based practice for this patient population.

**METHODS**

**Data Sources**

An electronic search was performed on PubMed, CINAHL, and SPORTDiscus databases from January 1, 2000 to December 31, 2010 using the following key words (either in isolation or in combination): patellofemoral pain syndrome, anterior knee pain, quadriceps exercise, quadriceps strength, hip exercise, hip strength, tape, taping, brace, bracing, orthosis, orthotics, and orthoses. A combined total of 878 articles were identified from the above-named data bases for review (Table 1).

<table>
<thead>
<tr>
<th>Table 1. Search strategy of PubMED, CINAHL, and SPORTDiscus from January 1, 2000 through December 31, 2010 to identify potential articles eligible for inclusion in the systematic review (all terms were separately entered into each database).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Key Words</strong></td>
</tr>
<tr>
<td>1 Patellofemoral pain syndrome or anterior knee pain</td>
</tr>
<tr>
<td>2 Quadriceps exercise or strength</td>
</tr>
<tr>
<td>3 Hip exercise or strength</td>
</tr>
<tr>
<td>4 Tape or taping</td>
</tr>
<tr>
<td>5 Brace or bracing</td>
</tr>
<tr>
<td>6 Orthosis or orthotics or orthoses</td>
</tr>
<tr>
<td>7 1 and 2</td>
</tr>
<tr>
<td>8 1 and 3</td>
</tr>
<tr>
<td>9 1 and 4</td>
</tr>
<tr>
<td>10 1 and 5</td>
</tr>
<tr>
<td>11 1 and 6</td>
</tr>
<tr>
<td>Total potential articles to be included in the systematic review</td>
</tr>
</tbody>
</table>
Study Selection
The authors selected evidence consistent with current relevant practice. To do this, the original search for evidence was limited and included only peer-reviewed manuscripts published within the past 10 years that utilized interventions lasting a minimum of 4 weeks. Studies not written in English, conference abstracts, theses, and dissertations were also excluded. Each researcher initially identified potential articles based on the abstract and confirmed appropriate inclusion by reviewing each article. The researchers discussed their search findings to ensure identification of relevant articles. Based on these criteria, the authors found 22 acceptable articles.

Data Extraction
The following data were extracted from each article: subject sample, intervention duration, intervention type, and pain outcomes. The authors also identified the research design used for each study (e.g., case study, quasi-experimental, or randomized control trial).

Data Synthesis
The quality of each study was evaluated using guidelines described by Ebell et al, who rate evidence for individual studies using a 3-level tier (Figure 1). The authors chose this taxonomy because it is patient-focused and allows the user to evaluate both a body of evidence and individual studies.

According to the Philadelphia Panel Evidence-Based Clinical-Practice Guidelines, pain represents an important impairment associated with PFPS and was the one impairment consistently reported in all the identified studies. Therefore, changes in pain were used as the benchmark for assessing and comparing study results. Using the available data from each article, the percentage change on a visual analog scale was calculated that best represented usual pain (e.g., pain normally experienced over a week), and the associated effect size for each intervention group was also reported (see Tables 2-6). Effect sizes were interpreted in the following manner: weak less than 0.40, moderate between 0.41 and 0.70, and strong greater than 0.70.

RESULTS
Hip Strengthening Exercise
Five investigations (Table 2) specifically examined the use of hip strengthening for the treatment of subjects with PFPS. With the exception of the case study (Level 3 evidence), all met the criteria for a Level 2 evidence rating and provided sufficient data to calculate effect sizes for changes in usual pain. Results from all the studies showed that subjects who participated in an exercise program targeting the hip abductors and hip external rotators reported at least a moderate reduction in pain (effect sizes ranging from 0.54 to 0.62). Additionally, Tyler et al included hip extensor and hip flexor exercises and reported an even greater improvement in pain (effect size = 0.96).

Quadriceps Strengthening Exercise
Ten investigations (Table 3) met the inclusion criteria and all received a Level 2 evidence rating. Findings from most of the studies (8/10) suggested at least a moderate (effect size ranges ranging from 0.37 to 0.59) to strong (effect size ranges ranging from 0.83 to 0.93) improvement in pain when subjects performed either non-weight bearing or weight bearing quadriceps exercise. Although Syme et al included hip extensor and hip flexor exercises and reported an even greater improvement in pain (effect size = 0.96).

Conversely, Bakhtiary & Fatemi reported minimal changes in pain for subjects who performed either a supine straight leg raise exercise (effect size = 0.31) or a single-leg squat exercise (effect size = 0.24) protocol. It is noteworthy that their subjects performed a less demanding exercise program compared to others included in this review (e.g., subjects in...
other investigations performed a higher exercise volume).

Some investigators incorporated quadriceps electrical stimulation45 (effect size = 0.50), biofeedback46 (effect size = 0.93), or simultaneous hip adductor activation43 (effect size = 0.42) with exercise, all of which provided no additional benefit from quadriceps exercise alone. Loudon et al13 only reported means but not standard deviations for their pain measures, which precluded our ability to calculate effect sizes. However, their subjects reported a 43% to 59% improvement in pain.

**Patella Taping**

Three studies (Table 4) that primarily used patella taping as an intervention met the established inclusion criteria. Crossley et al12 conducted the only study that met the Level 1 evidence criteria. This study was a randomized control trial that compared outcomes between subjects who received a true intervention (specialized exercise and corrective patella taping) and those who received a placebo intervention (sham ultrasound and loosely applied tape). Subjects in the treatment group experienced a strong reduction in pain (effect size = 0.81). Although not expected to receive benefit from the placebo intervention, controls reported a moderate improvement in pain (effect size = 0.53). Studies by Clark et al47 and Whittingham et al48 received a Level 2 evidence rating. They found that subjects who participated in quadriceps exercise in combination with either correctly or loosely applied tape reported a moderate-to-strong reduction in pain (effect sizes ranging from 0.54 to 0.98).

**Patella Bracing and Knee Bracing**

Two studies, both with Level 2 evidence ratings, met our inclusion criteria for patella bracing and knee bracing (Table 5). Lun et al17 found moderate improvements in

---

**Table 2. Summary of intervention studies aimed at hip strengthening.**

<table>
<thead>
<tr>
<th>Study, Type, Level of Evidence</th>
<th>Intervention</th>
<th>% decrease in usual pain</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boling et al17</td>
<td>Weight bearing exercises that focused on quadriceps and hip abductor strengthening (1 group n=14)</td>
<td>50</td>
<td>.60</td>
</tr>
<tr>
<td>Fukuda et al18 (Level 2)</td>
<td>Group 1(n=23): knee exercise only</td>
<td>31</td>
<td>.28</td>
</tr>
<tr>
<td>RCCT (Level 2)</td>
<td>Group 2 (n=20): knee and hip abductor and lateral rotator exercise</td>
<td>42</td>
<td>.54</td>
</tr>
<tr>
<td>Mascall et al31</td>
<td>Group 3 (n=21): control</td>
<td>-2†</td>
<td>.02</td>
</tr>
<tr>
<td>CS (Level 3)</td>
<td>Recruitment and endurance training of the hip, pelvis, and trunk muscles</td>
<td>Subject A: 100</td>
<td>N/A</td>
</tr>
<tr>
<td>Nakagawa et al32</td>
<td>Subject B: 71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCPT (Level 2)</td>
<td>Group 1(n=7): non-weight bearing and weight bearing quadriceps strengthening</td>
<td>15</td>
<td>.13</td>
</tr>
<tr>
<td></td>
<td>Group 2 (n=7): same as above plus transversus abdominus, hip abductor, and</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>hip lateral rotator strengthening</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tyler et al10</td>
<td>Non-weight bearing and weight bearing strengthening exercises designed to</td>
<td>45</td>
<td>.96</td>
</tr>
<tr>
<td>(Level 2)</td>
<td>progressively strengthen the hip muscles (1 group n=35)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CS = case study  
QE = quasi-experimental  
RCPT = randomized controlled pilot trial  
RCCT = randomized control clinical trial  
PFPS = patellofemoral pain syndrome  
N/A = unable to calculate since study design did not allow for reported means or standard deviations  
a = Level 2 (limited-quality patient-oriented evidence)  
b = Level 3 (other evidence)  
† Represents an increase in pain
<table>
<thead>
<tr>
<th>Study, Type, Level of Evidence</th>
<th>Intervention</th>
<th>% decrease in pain</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bakhtiar &amp; Fatemi (Level 2)</td>
<td>Group 1 (n=16): straight leg raise exercise Group 2 (n=16): single-leg semi-squat exercise</td>
<td>26</td>
<td>.31</td>
</tr>
<tr>
<td>Bily et al (Level 2)</td>
<td>Group 1(n=18): combination of non-weight bearing and weight bearing hip and knee strengthening exercise</td>
<td>75</td>
<td>.50</td>
</tr>
<tr>
<td>Dursun et al (Level 2)</td>
<td>Group 1(n=30): combination of non-weight bearing and weight bearing quadriceps exercise and stationary bike plus biofeedback Group 2 (n=30): as group 1 except no biofeedback</td>
<td>84</td>
<td>.93</td>
</tr>
<tr>
<td>Hazneci et al (Level 2)</td>
<td>All subjects performed isokinetic knee extension exercise (1 group n=24)</td>
<td>52</td>
<td>.83</td>
</tr>
<tr>
<td>Herrington &amp; Al-Sherhi (Level 2)</td>
<td>Group 1(n=15): non-weight bearing knee extension exercise Group 2 (n=15): seated leg press exercise Group 3 (n=15): control</td>
<td>44†</td>
<td>.56</td>
</tr>
<tr>
<td>Loudon et al (Level 2)</td>
<td>Group 1 (n=9): combination of non-weight bearing and weight bearing exercise performed in a PT clinic Group 2 (n=9): combination of non-weight bearing and weight bearing exercise performed as a home exercise program Group 3 (n=11): control</td>
<td>-20†β</td>
<td>.30</td>
</tr>
<tr>
<td>Syme et al (Level 2)</td>
<td>Group 1(n=21): selective vastus medialis oblique exercise Group 2 (n=22): general quadriceps femoris exercise</td>
<td>59</td>
<td>N/A</td>
</tr>
<tr>
<td>Witvrouw et al (Level 2)</td>
<td>Group 3 (n=20): control Group 1 (n=30): non-weight bearing knee extension exercise Group 2 (n=30): weight bearing knee extension exercise</td>
<td>45</td>
<td>.37</td>
</tr>
<tr>
<td>Witvrouw et al (Level 2)</td>
<td>Group 1 (n=24): non-weight bearing knee extension exercise</td>
<td>51</td>
<td>.45</td>
</tr>
</tbody>
</table>

QE = quasi-experimental  
RCT = randomized control trial  
RCTIT = randomized clinical trial  
PR = prospective randomized  
PFPS = patellofemoral pain syndrome  
PT = physical therapy  
N/A = unable to calculate since standard deviations were not reported  
a = Level 2 (limited-quality patient-oriented evidence)  
† Pain assessed using a 100-mm visual analog scale during a step-down test  
β Represents an increase in pain
pain with the use of either a patella brace (effect size = 0.55) or a neoprene knee sleeve (effect size = 0.40). In contrast to other findings regarding quadriceps exercise, they also found limited support for a home exercise program (effect size = 0.37) or a home exercise program in combination with patella bracing (effect size = 0.27).

Denton et al compared the use of the Protonics™ knee brace system to a traditional weight bearing quadriceps program. They did not assess pain in the same manner as the other studies (e.g. visual analog scale for usual pain) nor did they provide sufficient data to calculate effect sizes. However, Denton et al assessed pain during a step-down test (without bracing) and reported that subjects who performed exercise with the Protonics™ brace reported no pain during the step-down test following a 6-week intervention. Forty-one percent of the subjects who performed quadriceps exercise without the brace reported no pain during the same test.

Table 4. Summary of intervention studies incorporating patellar taping

<table>
<thead>
<tr>
<th>Study, Type, Level of Evidence</th>
<th>Intervention</th>
<th>% decrease in pain</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clark et al&lt;sup&gt;a&lt;/sup&gt; RCT (Level 2)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Group 1 (n=16): exercise, taping, and education</td>
<td>53</td>
<td>.54</td>
</tr>
<tr>
<td></td>
<td>Group 2 (n=16): exercise and education</td>
<td>61</td>
<td>.49</td>
</tr>
<tr>
<td></td>
<td>Group 3 (n=18): taping and education</td>
<td>31</td>
<td>.32</td>
</tr>
<tr>
<td></td>
<td>Group 4 (n=21): education</td>
<td>21</td>
<td>.39</td>
</tr>
<tr>
<td>Crossley et al&lt;sup&gt;12&lt;/sup&gt; RCT (Level 1)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Group 1 (n=36): exercise program and patellar taping</td>
<td>77</td>
<td>.81</td>
</tr>
<tr>
<td></td>
<td>Group 2 (n=35): placebo program (sham US and taping)</td>
<td>44</td>
<td>.53</td>
</tr>
<tr>
<td>Whittingham et al&lt;sup&gt;13&lt;/sup&gt; RCT (Level 2)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Group 1(n=10): patella taping and exercise program</td>
<td>100</td>
<td>.98</td>
</tr>
<tr>
<td></td>
<td>Group 2 (n=10): placebo taping and exercise program</td>
<td>88</td>
<td>.97</td>
</tr>
<tr>
<td></td>
<td>Group 3 (n=10): exercise program</td>
<td>76</td>
<td>.96</td>
</tr>
</tbody>
</table>

RCT = randomized control trial
PPFS = patellofemoral pain syndrome
PT = physical therapy
<sup>a</sup> = Level 1 (good-quality patient-oriented evidence)
<sup>b</sup> = Level 2 (limited-quality patient-oriented evidence)

Table 5. Summary of intervention studies incorporating patellar and knee bracing

<table>
<thead>
<tr>
<th>Study, Type, Level of Evidence</th>
<th>Intervention</th>
<th>% decrease in pain</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lun et al&lt;sup&gt;17&lt;/sup&gt; QE (Level 2)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Group 1 (n=34): home exercise program</td>
<td>48</td>
<td>.37</td>
</tr>
<tr>
<td></td>
<td>Group 2(n=32): patellar bracing</td>
<td>52</td>
<td>.55</td>
</tr>
<tr>
<td></td>
<td>Group 3 (n=32): home exercise program with patellar bracing</td>
<td>32</td>
<td>.27</td>
</tr>
<tr>
<td></td>
<td>Group 4 (n=31): home exercise program with knee sleeve</td>
<td>47</td>
<td>.40</td>
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<tr>
<td>Denton et al&lt;sup&gt;18&lt;/sup&gt; RCIT (Level 2)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Group 1 (n=17): weight bearing quadriceps exercise</td>
<td>41% reported no pain during the step-up test at the end of the study</td>
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<tr>
<td></td>
<td>Group 2 (n=17): weight bearing quadriceps exercise and Protonics™ brace</td>
<td>100% reported no pain during the step-up test at the end of the study&lt;sup&gt;†&lt;/sup&gt;</td>
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QE = quasi-experimental
RCIT = randomized clinical trial
PPFS = patellofemoral pain syndrome
<sup>a</sup> = Level 2 (limited-quality patient-oriented evidence)
<sup>†</sup> Insufficient data reported to calculate % decrease in pain and effect size
Foot Orthosis

Collins et al\textsuperscript{33} conducted the only randomized clinical trial (Level 1 evidence) to investigate foot orthosis use (Table 6). They divided a total of 157 subjects into one of the following groups: 1) corrective orthosis use and physical therapy exercise, 2) physical therapy exercise, 3) corrective orthosis use, and 4) flat insert use. Subjects who received corrective orthosis use and physical therapy exercise reported a moderate improvement in pain (effect size=0.50). However, weak improvements in pain occurred in subjects who only received corrective orthosis use (effect size =0.37) or physical therapy exercise (effect size=0.35). Subjects who only wore a flat insole reported a 2% increase in pain (effect size =0.02).

Johnston and Gross\textsuperscript{49} examined the effect of foot orthoses on pain by issuing study participants custom-made foot orthoses. They assessed pain using the Western Ontario and McMaster Universities Arthritis Index (WOMAC) subscales of pain. All subjects reported decreased pain at the 3-month assessment period. The investigators did not provide sufficient data to calculate percentage changes in pain or effect sizes.

DISCUSSION

PFPS is one of the most common and most challenging knee pathologies to manage. Unlike anterior cruciate ligament injury, which has a specific mechanism of injury and treatment approach, patients with PFPS receive various interventions. Overall, this review of the existing evidence showed that many treatment strategies may benefit these patients. While quadriceps exercise remained an important intervention, this review also supported the addition of hip strengthening. Evidence for other popular interventions, such as patellar taping, patellar bracing, knee bracing, and foot orthosis prescription, appeared to be less efficacious than exercise alone. The following sections explain these findings and provide clinical suggestions for integrating current evidence into clinical practice.

**Hip Strengthening Exercise**

Computer simulation\textsuperscript{50} and cadaveric models\textsuperscript{29,30} have shown that excessive hip adduction and/or excessive hip internal rotation can stress lateral patellofemoral joint structures as these motion increase the force applied to this area. These findings have led to subsequent studies examining hip function in patients with PFPS. Souza and Powers\textsuperscript{51} recently used traditional MRI to compare femoral structure (angle of inclination and torsion), muscle performance, and kinematics during running in this patient population. Overall, subjects with PFPS exhibited a 4.4° higher femoral angle of inclination but similar femoral anteversion as controls. They also demonstrated

<table>
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<tr>
<th>Table 6. Summary of intervention studies incorporating foot orthosis.</th>
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<tr>
<td>Study, Type, Level of Evidence</td>
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<tr>
<td>Collins et al\textsuperscript{33} (Level 1)*</td>
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<td>Johnston and Gross\textsuperscript{49} (Level 2)\textsuperscript{b}</td>
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</table>

RCT = randomized control trial  
OBS = observational study  
PFPS = patellofemoral pain syndrome  
PT = physical therapy  
\textsuperscript{a} = Level 1 (good-quality patient-oriented evidence)  
\textsuperscript{b} = Level 2 (limited-quality patient-oriented evidence)  
† Insufficient data reported to calculate % decrease in pain and effect size  
§ Subjects reported an increase in pain
hip weakness and greater femoral internal rotation during running, which they speculated would lead to increased lateral patellofemoral joint stress as shown in computer simulation
and cadaveric models. Step-wise regression revealed that decreased isotonic hip extensor endurance, not femoral structure, was the only predictor of increased hip internal rotation. These findings highlighted the importance of hip muscle performance to control femoral motion and corroborated results from other investigations that have reported decreased hip strength and altered lower extremity kinematics in this patient population.

The findings of the current review showed that hip strengthening exercise can benefit individuals with PFPS. Moderate evidence supports the use of hip abductor and external rotator strengthening, which may be further enhanced with the inclusion of exercises targeting hip flexion and hip extension. Although all works prescribed exercise for strengthening effects (i.e., 3 sets of 10 to 15 repetitions), emerging evidence has suggested the need to address muscle endurance. Therefore, clinicians should consider exercise dosage focusing on higher repetitions (i.e. 3 sets of 20 to 30 repetitions), especially in patients who participate in more demanding activities like running and jumping.

A limitation of most studies included in this review was a lack of attention toward neuromuscular factors such as activation amplitudes and timing differences between the hip and knee muscles. Preliminary evidence has inferred a potential delay in gluteus medius activation relative to the quadriceps that could affect hip function. Future investigations should examine the role of neuromuscular factors as well as changes in these factors following a hip exercise program.

**Quadriceps Strengthening**

Patients with PFPS historically have exhibited quadriceps weakness thought to contribute to abnormal patella tracking and patellofemoral joint irritation. Another possible contributing factor may be a reduction and/or delay in VMO activity relative to the VL that can cause excessive lateral patella tracking. To date, conflicting findings have existed as some researchers have reported a reduction and/or delay in VMO onset whereas others have not corroborated this pattern. Even if VMO dysfunction exists, consistent data have not supported selective activation of the VMO during exercise.

Findings agree with prior works regarding the importance of both weight bearing and non-weight bearing quadriceps strengthening for the treatment of PFPS. Consistent improvements in pain existed for subjects who performed general quadriceps strengthening exercises either in a weight bearing or non-weight bearing position. While clinicians may prefer weight bearing exercises that simulate functional activities, the use of non-weight bearing exercise may be equally beneficial, especially in patients with marked quadriceps weakness.

A key point to remember is that patients exercise in a pain-free manner. Clinicians should consider biomechanical stresses applied to the patellofemoral joint during non-weight bearing and weight bearing exercise. Patellofemoral joint stress is less from 90 to 45 degrees of knee flexion during non-weight bearing exercise and less from 45 to 0 degrees of knee flexion during weight bearing exercise. Finally, the additional use of neuromuscular electrical stimulation or biofeedback has no greater effect on pain than general quadriceps exercise alone.

**Patella Taping**

Patella taping is another intervention used to facilitate optimal patella alignment and tracking within the femoral trochlea. Often times, clinicians do not tape to a patient’s patella prior to exercise in hopes of decreasing pain and increasing VMO activation.

The results of this review support the use of taping in conjunction with exercise at least for the short-term treatment for PFPS. The mechanism by which patella taping may reduce symptoms remains elusive. Although initially theorized to improve patella alignment, prior works have shown taping to be ineffective for maintaining alignment during or immediately following exercise. Therefore, subjects may benefit from taping for proprioceptive input or neuromuscular control during the time of use.

Taping also may modulate pain to enable a patient to perform pain-free quadriceps exercise. Using MRI to assess patella kinematics, Derasari et al assessed
3 displacements (medial-lateral, superior-inferior, and posterior-anterior) and 3 rotations (lateral-medial tilt, extension-flexion, and posterior-anterior) in subjects with PFPS before and after McConnell taping. They found that taping primarily resulted in an inferior shift of the patella within the femoral trochlea. Increasing patella contact within the trochlea would reduce patellofemoral stress and may partially explain the positive results with tape use.

Interestingly, results from this review indicated that the manner of tape application (i.e. either applied in a corrective manner or applied loosely) may not necessarily influence its beneficial effects. Therefore, taping may have an important effect on the neuromuscular system rather than actually altering patella movement.

The results of this review did not support the use of taping over exercise alone since exercise appeared to be an important factor. It is noteworthy that taping has minimal effect in treating long-term symptoms associated with PFPS. Therefore, clinicians may consider patella taping on a short-term basis as needed to enable patients to perform pain-free exercise.

Patellar Bracing and Knee Bracing
Similar to taping, clinicians have used both patellar and knee bracing to prevent or correct patella malalignment within the femoral trochlea. Powers et al. examined pain and patella contact area in subjects with PFPS who donned the On-Track® (DJO, Vista, CA) and Patellar Tracking Orthosis® (BREG, Inc., Vista, CA) patella braces. They reported that all subjects reported less pain with brace use and that MRI revealed increased patella contact area with brace use. Powers et al concluded that bracing may have shifted patella contact within the femoral trochlea from areas of irritation to non-irritation. These findings may explain why Lun et al reported a moderate pain reduction in subjects who only wore a patellar brace.

The Protonics™ knee brace (Empi, St. Paul, MN) was the only knee brace included in this review. The brace was developed on the premise that iliopsoas and tensor fascia lata hypertonicity can lead to iliotibial band tightness and excessive lateral patella tracking. Based on principles of reciprocal inhibition, the brace manufacturer designed the brace to promote hamstring activation in order to normalize iliopsoas and tensor fascia lata tone.

The brace also is designed to produce a variable degree of a knee-extension moment. The manufacturer theorizes that pain occurs from increased patellofemoral joint compression from quadriceps activity. The knee-extension moment generated from brace use enables patients to perform weight bearing activities in a pain-free manner by reducing the amount of the quadriceps-produced compressive force. As patients demonstrate less patellofemoral joint irritation, the brace can be adjusted to provide a lower knee-extension moment and require a greater degree of quadriceps activity.

The current findings suggest that the Protonics™ knee brace may be an effective intervention to reduce pain. Like patellar taping, the exact mechanism for improvement remains unclear. Possible reasons for favorable outcomes may include redistributed patella stress, enhanced proprioceptive input, and improved neuromuscular control that allow subjects to perform pain-free quadriceps exercise. Additional studies are needed to conclusively determine the isolated benefits of the Protonics™ brace compared to pain-free exercise alone.

Foot Orthosis
Although clinicians routinely prescribe foot orthoses to minimize faulty lower extremity kinematics, few researchers have examined foot orthosis use for the treatment of PFPS over the past 10 years. Moreover, the exact mechanism for pain relief remains elusive.

No study included in this review examined kinematic changes during or following foot orthosis use, which limits the authors’ ability to determine an exact mechanism of change with wear. However, Barton et al. found very limited evidence for a foot orthosis to modify knee transverse plane kinematics for subjects with PFPS. Furthermore, prospective investigations have found inconsistent findings regarding an absolute relationship between increased foot pronation and the development of PFPS. Boling et al. identified increased navicular drop as a
significant risk factor for developing PFPS. These findings suggested that correction of excessive pronation would benefit this patient population. Conversely, Thijs and colleagues\(^{80,81}\) reported ambulation in a less pronated foot position as a predictor of PFPS. They concluded that the inability of the lower extremity to attenuate impact shock may contribute more to PFPS etiology. In summary, data gained from prospective studies suggest that PFPS may develop from either excessive or limited pronation.

Additional studies are needed to determine if foot orthosis use minimizes pain due to changes in kinematics (excessive pronation), kinetics (shock attenuation), or a combination of both. Moreover, evidence is needed to identify a cohort of patients likely to benefit from a foot orthosis. While isolated foot orthosis use may benefit some patients with PFPS,\(^{33,49}\) evidence gained from this systematic review suggests that orthosis use can augment the effects of exercise.\(^{79}\)

**Future Research**

Results from this systematic review support the continued use of quadriceps exercise and the incorporation of hip strengthening exercise. However, no data exist that conclusively confirm the effectiveness of isolated hip exercise over isolated quadriceps exercise. The author's findings also showed that certain interventions may benefit some but not all patients with PFPS. Information gained from this systematic review highlights the need to determine the isolated effects of hip strengthening on PFPS as well as identify specific cohorts of patients who may benefit from a specific intervention.

**CONCLUSION**

The purpose of this systematic review was to provide an update on the evidence for the conservative treatment of PFPS. Quadriceps exercise continues to represent an important treatment strategy. The results of this systematic review also support the addition of hip strengthening exercise. Clinicians have used biofeedback, patella taping, and foot orthoses as interventions for this patient population, and findings from this systematic review suggest that these strategies may augment the benefits gained from quadriceps exercise. Insufficient data regarding patella bracing limits the authors' ability to make a recommendation for its use.

**REFERENCES**


ABSTRACT

Background: There is little published information regarding postoperative management of patients with Chronic Exertional Compartment Syndrome (CECS). Reports of recurrence of symptoms following surgical decompression exist, and are not uncommon depending on the specific technique used. Recurrence suggests that more time and effort may need to be spent on implementing strategic post-operative rehabilitation management in order to avoid repeat surgical intervention or prolonged symptoms.

Objective: To summarize relevant literature regarding CECS and propose scientifically-based guidelines for rehab following compartment release with the rationale based on tissue healing, muscle loading, and scar tissue formation and consideration of all tissues contained in the involved compartment.

Literature review: A literature search was performed in PubMed, SPORTDiscus, CINAHL, PEDRO, and Google Scholar using the phrase: “chronic exertional compartment syndrome.”

Results: No specific rehabilitation guidelines following surgical compartment release for lower extremity CECS were found in the literature search performed for this clinical commentary.

Discussion: The development of the proposed post-operative guidelines may allow for improved long-term outcomes following anterior compartment release.

Summary: Adequate description of long-term follow-up of outcomes following compartment release for CECS is lacking in current literature. The proposed guidelines for rehab following compartment release include consideration of tissue healing, muscle loading, scar tissue formation, and consideration of soft tissues contained in the involved compartment. Utilization of the proposed guidelines may allow for future research to be performed in order to assess outcomes following surgical intervention for CECS.

Key Words: chronic exertional compartment syndrome, tissue healing parameters
BACKGROUND/INTRODUCTION
Compartment syndrome occurs when increased intramuscular pressure (fluid hydrostatic pressure in the interstitial space of a skeletal muscle tissue) impedes local muscle blood flow thereby impairing neuromuscular function of tissues within the specific compartment.1 Chronic Exertional Compartment Syndrome (CECS) is a reversible form of abnormally increased intramuscular pressure that occurs during exercise/exertion secondary to osteofascial tissues that are noncompliant with muscle volume expansion during exercise.1,2 Other terms used to describe the condition may include: anterior tibial pain, anterior compartment syndrome, recurrent compartment syndrome, idiopathic compartment syndrome, non-traumatic compartment syndrome of the lower extremity, fasciitis, pain in limb, swelling in limb, transient paralysis of limb, and disorder of soft tissue.1 Although compartment syndrome can exist wherever a compartment is present (thigh, forearm, upper arm, foot, hand, lumbar spine, abdomen, buttock), the anterior and lateral compartments of the lower leg are most commonly affected. This clinical commentary will focus on the anterior compartment of the lower leg, and on the open fasciotomy surgical technique. The principles described herein may, however, be applied to other lower leg compartments and surgical techniques.

CECS is often initially treated conservatively with rehabilitation. However, surgical decompression of the fascial compartment is often the subsequent treatment of choice for active individuals. There is little evidence in the literature on postoperative management of patients with CECS. Recurrence rates following various decompression techniques range from 3-17%. Over 35% of patients who undergo partial fasciectomy have reoccurrence of compartment syndrome or development of compartment syndrome in a different lower leg compartment, causing a reduction in exercise levels.3,4,5 This recurrence rate suggests that more time and effort needs to be spent on implementing strategic post-operative rehabilitation management after compartment release, in order to avoid additional surgical intervention or prolonged symptoms. The objective of this clinical commentary is to summarize the published evidence and propose scientifically-based guidelines for rehab following anterior compartment release with the rationale based on tissue healing, muscle loading, scar tissue formation, and consideration of all tissues contained in the involved compartment. Utilization of the proposed guidelines may allow for future research to be performed in order to assess outcomes following surgical intervention for CECS.

LITERATURE REVIEW
Published research and expert commentary articles were identified using both medical and rehabilitation electronic databases. All relevant articles regarding surgical rehabilitation following decompression of the anterior compartment were reviewed. A literature search was performed utilizing PubMed, SPORTDiscus, CINAHL, PEDRO, and Google Scholar. All references that were available by the first week of October 2010 were included. Initial searches were performed using the phrase: “chronic exertional compartment syndrome.” Attempts to perform searches without the entire phrase resulted in access to a wide variety papers that addressed varied compartments as well as those addressing acute compartment syndromes. Therefore, the results from the searches with use of the quotation separated phrase were then combined using the Boolean connectors “or” and “and” followed by (1) “rehabilitation,” (2) “treatment,” or (3) “postoperative.” From each database, titles, abstracts, and articles were reviewed in order to identify any articles that included information regarding postoperative rehabilitation or outcomes following surgical decompression of CECS of the anterior compartment of the lower leg. Additional citations were identified by assessing the references contained within each article. Finally, an attempt was made to perform the same search while using the other terms used to describe the condition including: anterior tibial pain, anterior compartment syndrome, recurrent compartment syndrome, idiopathic compartment syndrome, non-traumatic compartment syndrome of the lower extremity, fasciitis, pain in limb, swelling in limb, transient paralysis of limb, and disorder of soft tissue.

RESULTS
The electronic searches produced the following number of articles on each of the following databases: PubMed (99), SPORTDiscus (67), CINAHL (43), PEDRO
Articles that did not fit the objective of the clinical commentary were omitted from the review. These included articles regarding acute compartment syndrome as well as chronic exertional compartment syndromes occurring in the foot, other lower leg compartments, thigh, forearm, hand, and lumbar spine.

No specific criterion-based guidelines following surgical compartment release for lower extremity CECS (in any compartment) were found. Some time-based guidelines for general return to sport/play after CECS were found however there was some inconsistency regarding both the timelines of treatment and type of activity/sport being described. Furthermore, none of the guidelines specifically referenced or referred to time required for tissue healing, demands of eccentric muscle loading, effects of scar tissue formation, and consideration for all tissues (particularly nerve) contained within a compartment.

The U.S. Department of Health & Human Services' Agency for Healthcare Research and Quality has a searchable database of clinical practice guidelines called the National Guidelines Clearinghouse. The guidelines represented there are linked to a particular term derived from the U.S. National Library of Medicine’s classification for diseases/conditions and treatments/interventions. Searching the National Guidelines Clearinghouse also yielded no guidelines for this diagnosis.

ANATOMY
The lower leg is comprised of four universally described compartments (anterior, lateral, superficial posterior, and deep posterior). Figure 1 shows a cross section of the compartments of the lower leg. Each compartment is surrounded by osseofascial structures that define the various compartments in the extremities. The osseofascial compartments have relatively fixed volumes. The anterior compartment contains the tibialis anterior, extensor digitorum longus, extensor hallucis longus and peroneus tertius muscles in addition to the anterior tibial artery and vein and deep peroneal nerve. The lateral compartment contains the peroneus longus and brevis muscles, a branch of the anterior tibial artery and vein as well as the superficial peroneal nerve. The superficial posterior compartment contains the gastrocnemius, soleus, and plantaris muscles as well as a branch of the tibial artery and vein and the sural nerve whereas the deep posterior compartment contains the tibialis posterior, flexor digitorum longus, flexor hallucis longus, and popliteus muscles in addition to the posterior tibial artery and vein and tibial nerve.

ETIOLOGY AND PATHOPHYSIOLOGY
The exact physiological cause of CECS remains unclear but it is thought to be multi-factorial. Contributors to CECS may include: muscle hypertrophy, fascial thickness or stiffness, stimulation of fascial sensory stretch receptors, decreased venous return, microtraumatic
muscular injuries, and clinical myopathies. Intrinsic factors are likely contributory and may include leg length discrepancy and varus or valgus malalignment. Extrinsic factors are also likely contributory and may include: decreased strength, endurance or flexibility; incorrect motor control patterns; and inappropriate training volume, intensity, or frequency.

Turnipseed, Hurschler, and Vanderby (1995) found muscle fascia surrounding the anterior compartment in those with CECS to be stiffer and thicker than those unaffected by the condition. Approximately 10-60% of athletes with CECS symptoms have small fascial defects in the lower leg. Birtles, Rayson, Jones, Padhiar, et al compared high force eccentric contractions of the anterior tibialis muscles in patients with CECS to healthy controls. The CECS patients had increased mean pain with dorsiflexion and palpation 24 and 48 hours following exercise, suggesting that some patients with CECS may be more susceptible to pain with eccentric contractions. Eccentric activity may be the cause of damage and inflammation of connective tissue given that myofibril change and edema of fast-twitch fibers occurs following eccentric activity. Brennan and Kane documented that in post-pubertal athletes, exercise that biases eccentric contraction (downhill running for example) may decrease fascial compliance over time and contribute to CECS.

Brennan and Kane also demonstrated that muscle volume increases by 20% during cardiovascular exercise, and lower extremity intramuscular pressure can exceed 500 mm Hg during contractions. Peripheral muscles perfuse oxygen when muscle is relaxed and the arterial/venous gradient subsequently increases. The gradient must be at least 30 mm Hg to overcome intramuscular resting pressure. If compartment pressure exceeds 30 mm Hg the perfusion gradient does not exist.

Strenuous exercise can cause microtrauma to muscle tissue. Those affected by CECS do have greater deoxygenation of muscle during exercise and delayed reoxygenation of muscle after exercise. Styf describes how muscle and capillary bed inflammation may increase fluid flow from the capillaries to the interstitial space thereby increasing the volume and fluid pressure of the space. When increased compartment pressure persists, pain, paresthesia, and muscle weakness can develop. The degree of elevated pressure however does not correlate with the degree of symptoms or predict outcomes following surgical fasciotomy. Hutchinson and Ireland concluded that elevated compartment pressure increases venous pressure, which in turn decreases the arterial-venous gradient thereby reducing blood flow within the compartment. Reduced blood flow can lead to ischemia however this is not universally accepted as the cause for CESC. Other theories include increased facial thickness and stiffness, increased pressure as a source for pain receptor stimulation in the fascia and periosteum, and increased lactate in the bloodstream secondary to decreased perfusion within a compartment.

**PREVALENCE**

The incidence of CECS in those with chronic exercise-induced anterior lower leg pain ranges from 14-27%. Seventy percent of patients with chronic exertional compartment syndrome in the anterior compartment are runners. The condition is nearly evenly split between males and females; early reports showed predominance among men but the proportion of females with CECS is rising. Women may respond less well to operative measures. Incidence of CECS is nearly equal in recreational and elite athletes and the median age of those who present with CECS is 20 years. The anterior and lateral compartments of the lower leg are most commonly affected and have better outcomes with surgical treatment, in comparison to the posterior compartment.

**DIAGNOSIS**

Careful evaluation is vital when assessing an athlete with complaints of "shin pain". Differential diagnosis may include muscle/tendon involvement (CECS, muscle strain, fascial hernia, tendinopathy), bone involvement (medial tibial stress syndrome, stress fracture), vascular involvement (popliteal artery entrapment syndrome, intermittent claudication, venous insufficiency), neurologic involvement (peripheral or central nerve entrapment/impingement, referred symptoms from proximal joint), tumor, or infection.

CECS has been reported in the forearm, thigh, hand and foot, however, 95% of cases occur in the lower leg. Bilateral symptoms in the legs occur in 85-95% of those affected.
Subjectively, those affected with CECS often complain of dull, aching, or cramping pain localized to the compartment affected in the lower extremity at the same duration of time (minutes) following the initiation of each episode of exercise. On clinical examination, muscle hypertrophy and pallor may be noted. Compartment muscles may be firm to palpation, while distal pulses are typically normal. Passive stretching can increase pain when pressures are elevated in the affected compartment. Nerve dysfunction may impair sensation to light touch as well as strength particularly following an exercise test; paresthesia may also be present. The gold standard test used to confirm the diagnosis of CECS is intracompartmental pressure testing, performed first at rest and then following exercise. Normal resting intracompartmental pressure is between 0-8 mm Hg. Resting compartment pressure greater than 15 mm Hg, post-exercise compartment pressure (measured one minute after exercise cessation) greater than 30 mm Hg, or post-exercise compartment pressure (measured five minutes after exercise cessation) of greater than 20 mm Hg are diagnostic for CECS in all compartments. Furthermore, compartment pressures that fail to return to baseline within 15 minutes post-exercise are considered borderline for CECS diagnosis.

**TREATMENT**

Many physical therapists are first contact providers who provide direct access (DA) intervention. They, along with other primary care providers (PCP), may benefit from direction regarding optimal care for CECS.

CECS often is initially treated conservatively with rehabilitation, ranging in duration from a few weeks to several months. Surgical decompression of the fascial compartment may be the treatment of choice for active individuals if conservative intervention fails. Although conservative treatment appears to have minimal long-term value in published reports in the literature, there are no randomized controlled studies to investigate the effectiveness of conservative management. The proposed treatment algorithm, found in Figure 2, outlines management of CECS. If CECS is suspected by the PCP or physical therapist, a clinic visit for compartment syndrome evaluation by a Sports Medicine or Vascular Physician specialist may be warranted.

**Surgical Management of CECS**

Unlike acute compartment syndrome, the treatment of CECS is non-emergent. Furthermore, the surgical approach may be less extensive, involving only the involved compartments. The suggested resting pressure considered significant and that indicates the need for surgery for those with CECS is debated in the literature. Minimum elevated pressure for consideration of surgery is documented between 30 and 55 mmHg, but there is no clear consensus; one author has proposed that the interpretation should be associated with the individual’s actual diastolic blood pressure.

Currently surgical management is the treatment choice, after the failure of conservative care, in active patients with CECS; however, there is variety among the surgical techniques that are used. Various surgical decompression techniques have been described in the literature including: open fasciotomies with 1 or 2 incisions, minimally invasive subcutaneous fasciotomies through 1 or 2 incisions, fasciotomies with partial fasciectomies, and subcutaneous endoscopic fasciotomies with and without the use of balloon dissectors. An open fasciotomy involves 1-2 large incisions where fascial tissue is cut. A minimally invasive subcutaneous fasciotomy involves incision of fascia blindly via small skin incision(s). A fasciotomy with partial fasciectomy is when a portion of the fascia is removed. A subcutaneous endoscopic fasciotomy with the use of a balloon dissector creates an optical cavity to allow visualization of the fascia and
space to perform the dissection with endoscopic equipment. There appears to be no consensus on a superior approach in terms of postoperative outcome. Since many athletes have bilateral CECS, bilateral fasciotomies may be considered. Bilateral simultaneous fasciotomies may be considered safe and effective with low complication rates and adequate ability to return to sport participation.20 Surgical treatment can be performed as an outpatient procedure under local anesthesia.12

Reports of improvement following anterior or lateral compartment release range between roughly 80-100%.5,10 Release of the deep posterior compartment has not been as successful with success being reported in only 50-65% of those who undergo the procedure.5,10 Complications following compartment release exist and include hemorrhage, hematoma, deep vein thrombosis, wound infection, skin breakdown, nerve entrapment or injury, swelling, vascular injury, residual weakness, and lymphocele.1,3,5,8,10 Incidence of complications ranges from 4.5-13%; recurrence of symptoms occurs in 7-17% of surgical cases.5

Results of surgical fasciotomy and rate of return to sport has not been consistent.12 A lower success rate has been documented for women following anterior compartment fasciotomy as well as following fasciotomy of the posterior compartment in patients of either sex.1 Follow-up regarding outcomes following compartment release is lacking in the literature. The lack of outcome assessment raises questions regarding the specifics of who does well long-term and who does not. Recurrence rates as high as 17% have been documented following various decompression techniques.3,5 However, 36% of patients had recurrence of compartment syndrome or development of a different lower leg compartment syndrome after partial fasciotomy of the anterior compartment, thereby causing a reduction in their ability to exercise.4 Recurrence may be due to incorrect diagnosis, inadequate release, failure to release a compartment thought to be asymptomatic, nerve compression by an unrecognized fascial hernia, and development of prolific scar tissue.3 Abnormal scarring of the fascia or overlying skin has been found to occur following surgical release.10 Approximately 10% of patients require a revision surgery.1 Of note, although a fasciotomy is often effective in eliminating the pathological increase in compartment pressure, it does not treat the elusive initial cause of the syndrome.1

**Rehabilitation**

The proposed treatment algorithm in Figure 2 suggests initially attempting conservative treatment for 6-8 weeks in all cases of CECS. Conservative management of CECS may include: reduction in or modification of activity, massage, other specific soft tissue mobilization and manipulation techniques, including myofascial stretching, taping, orthotic inserts, footwear modification, stretching, and non-steroidal anti-inflammatory medications.10 In theory soft tissue mobilization, for example myofascial stretching, would facilitate increased fascial compliance which would address the proposed pathophysiology involving increased facial thickness and stiffness and increased pressure as a source for pain receptor stimulation in the fascia. There is inconsistency in the literature regarding efficacy of all types of conservative treatment. Many authors argue that conservative treatment will not bring definitive relief of symptoms, however most research on CECS has been conducted by surgeons.8,12 In a pilot study by Blackman, et al involving a 5-week course of massage for those with CECS of the anterior compartment, there was no significant difference in post-exercise compartment pressure following treatment. However, there was a significant increase in dorsiflexion work able to be performed prior to the onset of pain, measured using a Cybex isokinetic dynamometer.21

A carefully planned and implemented rehabilitation program is important for a patient to achieve optimal functional outcomes post-operatively.22 The proposed guidelines for rehabilitation following compartment release include scientific rationale based on tissue healing, muscle loading, scar tissue formation, and consideration of all tissues contained in the involved compartment. The recommendations given are based on the initial use of “PRICE” (protection, rest, ice, compression, and elevation), with progression to re-establishing range of motion (ROM) and soft tissue mobility, incorporating stretching, neurodynamic mobilizations, strengthening, and finally, incorporating biomechanical analysis of the athlete during sport specific activity.
**Protection, Rest, Ice, Compression, and Elevation:**
This approach is used during the proliferation phase of tissue repair which typically lasts approximately 3-20 days. During this phase, the tensile strength of the tissue can be as low as 15% of normal tissue, making protection of the tissue essential.\(^\text{23}\) Fasciotomy may cause significant edema and hematoma formation,\(^\text{14}\) therefore, rest, ice, compression, and elevation are crucial for swelling control.

**Range of Motion and Soft Tissue Mobility:**
During the proliferation phase of tissue repair, the injured area has the greatest amount of collagen; edema and excessive stress on the healing area may result in additional inflammation and deposition of collagen. The excessive collagen can result in excessive scarring which may limit functional outcome.\(^\text{23}\) Wound contraction begins at approximately 5 days after injury and peaks at about 2 weeks.\(^\text{23}\) The maturation phase occurs from day 9 onward and is the longest phase in the healing process. Several factors determine the rate of maturation as well as the final characteristics of the scar tissue, including fiber orientation and balance of collagen synthesis and lysis.\(^\text{23}\) Collagen in scar tissue is less organized than that of uninjured tissue. Internal and external stresses placed on tissue during the maturation phase can determine the final tissue structure.\(^\text{23}\) Muscle tension, joint movement, soft tissue loading, fascial gliding, temperature changes, and mobilization are forces proposed to affect collagen structure.\(^\text{23}\) Post-operative active and passive range of motion of the ankle and knee will assist in prevention of formation of hematoma and scar near the fasciotomy incision.\(^\text{13}\) Early motion is beneficial to prevent scarring and contracture that may occur with open decompression in addition to the existing tissue damage that occurs from CECS.\(^\text{12}\) Surgery may be ineffective if fascia heals in original position; recurrences have been attributed to restrictive scarring at the fasciotomy site.\(^\text{13,15}\)

Sensitization (hyper sensitivity) is caused by strengthening of responses to perceived injurious stimuli. It can be short-term or long-term; mechanisms for long-term memory of sensitization involve the same cells as short-term memory but reflect structural changes in the cells.\(^\text{24}\) Animals with long-term sensitization had twice as many synaptic terminals, increased dendrites in postsynaptic cells, and a 40-65% increase in the number of active zones at synaptic terminals than untrained animals.\(^\text{24}\) The use of a desensitization approach may decrease anxiety and fear of touch over areas of scar tissue. A treatment progression involving brushing material over the skin could initially involve soft, light, fabric with progression toward stiffer, thicker fabric. Brushing is slow and purposeful, it should not damage the skin.

**Stretching:**
Passive stretching increases pain when pressures are elevated in the respective compartment\(^\text{10,12,14}\) which suggests that muscle stretching may also result in stretching of the compartment fascia. The intensity, frequency, timing, and duration of stretching are critical to obtain anti-fibrotic effects.\(^\text{25}\) Scar tissue responds to low load, long duration stretch for permanent change.\(^\text{23}\) There are several types of cutaneous receptors in the skin including mechanoreceptors, thermoreceptors, and nocioceptors. Mechanoreceptors include pacinian corpuscles, Merkel’s discs, Meissner’s corpuscles, Ruffini endings, and lanceolate endings around hair follicles. Ruffini endings detect tension deep in the skin and Merkel’s discs detect sustained touch and pressure. Muscle spindles, which are found in the belly of skeletal muscles, send signals to the nervous system via afferent fibers and are controlled by the central nervous system via efferent fibers. The group Ia afferents have a low threshold to stretch and follow changes in length easily; they code the rate of stretch (dynamic response) and the length of muscle at the end of a stretch (static response).\(^\text{24}\) The American College of Sports Medicine (ACSM) recommended flexibility training parameters include a daily stretching dose of 180 seconds, with a frequency of 3 days/week. Active or passive technique and variation in single stretch duration (15, 30, or 45 seconds) resulted in no significant difference in flexibility after 12 weeks of stretching.\(^\text{26}\)

**Neurodynamic Mobilizations:**
Butler\(^\text{27}\) proposed that stretch pain or paresthesia symptoms are a result of tension being placed on some component of the nervous system. Restriction of movement can be from inflammation and scarring between the nerve and tissue through which it runs.\(^\text{27}\) Treatment involving neurodynamic mobilizations including sliding and tensioning techniques are
important to enhance nerve gliding and restore neural tissue mobility, and have been shown to be beneficial for ulnar nerve entrapment.\textsuperscript{19} Given the amount of inflammation and scarring which may be present within a compartment, this type of neurodynamic intervention may be beneficial in conservative treatment as well as following surgical compartment release for CECS. Intervention should be focused on the involved nerves within a specific lower extremity compartment. The focus of this clinical commentary is on the anterior compartment and therefore neurodynamic interventions are aimed at the deep peroneal nerve.

**Strengthening:**
Preoperatively, patients with CECS of the anterior compartment are weaker than control subjects during dorsiflexion isometric exercise, and exhibit lower isokinetic muscle strength in ankle dorsiflexors compared to normal individuals.\textsuperscript{8,16} Postoperatively, a decrease in muscle contractile force may occur due to altered biomechanics of the muscle following fascial incision.\textsuperscript{8} Decreased dorsiflexion strength pre-operatively may lead to recurrence of CECS of the anterior compartment post-operatively unless appropriate strengthening is implemented.\textsuperscript{8} Because intramuscular pressure at rest is elevated following eccentric muscular activity as compared to concentric muscular activity,\textsuperscript{1} eccentric muscle strengthening should initially be avoided postoperatively. The guidance of a skilled professional is recommended for methodical progression of strengthening exercises.

**Biomechanical Analysis of Specific Activity:**
Development of anterior compartment CECS has been described after implementation of a new skating method of cross-country skiing, when compared to the classic skiing technique. The skating technique involves kicking diagonally versus the classic skiing method in which movement remains primarily in the sagittal plane. This finding highlights the importance of lower extremity biomechanical assessment prior to return to any specific sport or activity, as the precise technique of a sport may involve biomechanical movement in multiple planes of motion.\textsuperscript{1} A forceful heel strike results in high pressure in the tibialis anterior muscle associated with eccentric muscle contraction during running.\textsuperscript{1} This further supports the need for biomechanical assessment of any activity that the athlete participates in, in order to avoid reoccurrence of symptoms. Given that the cause of CECS is thought to be multifactorial, intrinsic factors including leg length discrepancy, varus or valgus malalignment, foot biomechanics, and motor control patterns should be addressed postoperatively.\textsuperscript{8} Extrinsic factors including training volume, intensity, or frequency should also be considered in addition to activity technique, training surface, and footwear.\textsuperscript{8}

It is vital to assess patient outcomes before and after a formal course of rehabilitation following surgical release of the anterior compartment, given that this is lacking in current literature. Following the proposed guidelines will assist in data collection to better assess outcomes following this type of procedure. The Foot and Ankle Ability Measure (FAAM) is the recommended outcome assessment instrument as it has proven to be a reliable, responsive, and valid measure of physical function for individuals with a broad range of musculoskeletal disorders of the lower leg, foot, and ankle.\textsuperscript{28} The FAAM consists of a 21-item activities of daily living subscale, as well as an 8-item sports subscale. The minimal clinically important differences are 8 and 9 points for the ADL and sports subscales, respectively.\textsuperscript{28}

**Proposed Scientifically-Based Rehabilitation Guidelines Following Open Fasciotomy with Anterior Compartment Release\textsuperscript{1,2,5,10,12,13,14,15,19,17,22,23,29,30,31}**

**PHASE I: Protection and Mobility (2-3 weeks Post-operatively).**

**PHASE II: Light Strengthening (Begin after meeting Phase I criteria, approximately 3-4 weeks following surgery).**

**PHASE III: Progression of Strengthening (Begin after meeting Phase II criteria, approximately 4-6 weeks following surgery).**

**PHASE IV: Impact/Sport Training (Begin after meeting Phase III criteria, approximately 8-12 weeks following surgery).**
Phase I Appointments

- Physician appointment: 5-10 days post-operatively for suture removal, no drain used
- Rehabilitation appointments begin 5-7 days after surgery, continue 1 time every 5-10 days

Phase I Rehabilitation Goals

- Administer FAAM (ADL and sport subscales)
- Protection of the post-surgical compartment
- Minimize postoperative swelling; lower extremity circumference within 2 cm of uninvolved side
- Instruction in safe positioning and limb self-management
- Able to lift leg involved leg in all directions in standing without pain or compensation.
- Restore ability to control leg in open and closed kinetic chain during gait.
- Non-antalgic gait on level surface with full weight bearing and no assistive device at >2 mph with equal step length bilaterally.

Phase I Precautions

- Use axillary crutches for gait with progressive weight bearing as tolerated, keeping pain at or below 2/10 on visual analog scale (1-2 weeks).
- Avoid any activity which causes increased swelling (for example: extended sitting or sitting with lower extremity in dependent position, tight clothing proximal to surgical release, and hot pack or bath).
- Avoid any friction on new scar formation (for example: crossing legs, tight clothing, pushing object with legs or using weight machine that presses into skin over incision site).
- Avoid any impact activity including running, jumping, or hopping (6-8 weeks).

Phase I Suggested Therapeutic Exercise

- Active ankle range of motion immediately to maintain extensibility of soft tissues as they heal to prevent postoperative contractures (include ankle PF, DF, inversion and eversion, knee flex and ext), begin with 10 repetitions in each direction, 1-2 times/day and progress number of repetitions as tolerated. May also consider initiation of open kinetic chain strengthening; begin with theraband level 1-2, 1-2 sets of 10 in each direction, 1 time/day, at 3 weeks post-op. Progress as tolerated.
- Quadriceps sets for isometric strengthening. Begin with 5-10 second holds, 10 repetitions, 1-2 times/day. Progress hold time or repetitions followed by progression into short arc or long arc quad or straight leg raise.
- Leg lifts for hip strength: hip flexion, abduction and extension. Begin in supine, side lying and prone, respectively, and progress into standing. 1 set of 10 in each direction, 1-2 times/day. Progress as tolerated.
- Elevation of the operative extremity (above level of heart) begin with 30-40 minutes every 1-2 hours and modify as needed, ice 15-20 minutes with barrier between skin and icepack, and compression garment (Ace wrap or TED stocking), as needed, for swelling control
- Active muscle pumping exercises at distal/ankle joint while lower extremity is elevated on wall to assist with venous return and swelling. 1-2 minutes of active ankle pumping; 3-6 times/day or as needed for swelling control. (Figure 3)
- Gentle distal-to-proximal massage to assist with venous return and swelling. Can perform with leg elevated on wall. Avoid contact with incisions. 3-5 minutes, 1-2 times/day or as needed to assist with swelling control.

Phase I Cardiovascular Exercise

- Upper body circuit training or upper body ergometer, as able. Begin with 5-10 minutes, 1-2 times/day, and progress as able.

Progression Criteria to Phase II

- Patient may progress to Phase II if they have met the above stated goals.

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**Table 1: PHASE I: Protection and Mobility (Surgery to 2-3 weeks).**

<table>
<thead>
<tr>
<th>Category</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase I Appointments</td>
<td>Physician appointment: 5-10 days post-operatively for suture removal, no drain used</td>
</tr>
<tr>
<td></td>
<td>Rehabilitation appointments begin 5-7 days after surgery, continue 1 time every 5-10 days</td>
</tr>
<tr>
<td>Phase I Rehabilitation Goals</td>
<td>Administer FAAM (ADL and sport subscales)</td>
</tr>
<tr>
<td></td>
<td>Protection of the post-surgical compartment</td>
</tr>
<tr>
<td></td>
<td>Minimize postoperative swelling; lower extremity circumference within 2 cm of uninvolved side</td>
</tr>
<tr>
<td></td>
<td>Instruction in safe positioning and limb self-management</td>
</tr>
<tr>
<td></td>
<td>Able to lift leg involved leg in all directions in standing without pain or compensation.</td>
</tr>
<tr>
<td></td>
<td>Restore ability to control leg in open and closed kinetic chain during gait.</td>
</tr>
<tr>
<td></td>
<td>Non-antalgic gait on level surface with full weight bearing and no assistive device at &gt;2 mph with equal step length bilaterally.</td>
</tr>
<tr>
<td>Phase I Precautions</td>
<td>Use axillary crutches for gait with progressive weight bearing as tolerated, keeping pain at or below 2/10 on visual analog scale (1-2 weeks).</td>
</tr>
<tr>
<td></td>
<td>Avoid any activity which causes increased swelling (for example: extended sitting or sitting with lower extremity in dependent position, tight clothing proximal to surgical release, and hot pack or bath).</td>
</tr>
<tr>
<td></td>
<td>Avoid any friction on new scar formation (for example: crossing legs, tight clothing, pushing object with legs or using weight machine that presses into skin over incision site).</td>
</tr>
<tr>
<td></td>
<td>Avoid any impact activity including running, jumping, or hopping (6-8 weeks).</td>
</tr>
<tr>
<td>Phase I Suggested Therapeutic Exercise</td>
<td>Active ankle range of motion immediately to maintain extensibility of soft tissues as they heal to prevent postoperative contractures (include ankle PF, DF, inversion and eversion, knee flex and ext), begin with 10 repetitions in each direction, 1-2 times/day and progress number of repetitions as tolerated. May also consider initiation of open kinetic chain strengthening; begin with theraband level 1-2, 1-2 sets of 10 in each direction, 1 time/day, at 3 weeks post-op. Progress as tolerated.</td>
</tr>
<tr>
<td></td>
<td>Quadriceps sets for isometric strengthening. Begin with 5-10 second holds, 10 repetitions, 1-2 times/day. Progress hold time or repetitions followed by progression into short arc or long arc quad or straight leg raise.</td>
</tr>
<tr>
<td></td>
<td>Leg lifts for hip strength: hip flexion, abduction and extension. Begin in supine, side lying and prone, respectively, and progress into standing. 1 set of 10 in each direction, 1-2 times/day. Progress as tolerated.</td>
</tr>
<tr>
<td></td>
<td>Elevation of the operative extremity (above level of heart) begin with 30-40 minutes every 1-2 hours and modify as needed, ice 15-20 minutes with barrier between skin and icepack, and compression garment (Ace wrap or TED stocking), as needed, for swelling control</td>
</tr>
<tr>
<td></td>
<td>Active muscle pumping exercises at distal/ankle joint while lower extremity is elevated on wall to assist with venous return and swelling. 1-2 minutes of active ankle pumping; 3-6 times/day or as needed for swelling control. (Figure 3)</td>
</tr>
<tr>
<td></td>
<td>Gentle distal-to-proximal massage to assist with venous return and swelling. Can perform with leg elevated on wall. Avoid contact with incisions. 3-5 minutes, 1-2 times/day or as needed to assist with swelling control.</td>
</tr>
<tr>
<td>Phase I Cardiovascular Exercise</td>
<td>Upper body circuit training or upper body ergometer, as able. Begin with 5-10 minutes, 1-2 times/day, and progress as able.</td>
</tr>
<tr>
<td>Progression Criteria to Phase II</td>
<td>Patient may progress to Phase II if they have met the above stated goals.</td>
</tr>
</tbody>
</table>
Figure 3. Active muscle pumping exercise at ankle joint with lower extremity elevated on wall to assist with venous return and swelling

Table 2: PHASE II: Light Strengthening (begin after meeting Phase I criteria, approximately 3-4 weeks following surgery)

<table>
<thead>
<tr>
<th>Category</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase II Appointments</td>
<td>Rehabilitation appointments are 1 time per week on average</td>
</tr>
<tr>
<td>Phase II Rehabilitation Goals</td>
<td>Lower extremity circumference within 1 cm of uninvolved side</td>
</tr>
<tr>
<td></td>
<td>Incision is well healed</td>
</tr>
<tr>
<td></td>
<td>Minimize muscle atrophy and flexibility deficits in anterior/involved compartment</td>
</tr>
<tr>
<td></td>
<td>Single leg stance control with eyes open on unstable surface for 30-60 seconds</td>
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<tr>
<td></td>
<td>Full flexibility of gastrocnemius (ankle DF with knee extended): 15-20 degrees</td>
</tr>
<tr>
<td></td>
<td>Maintain motion and strength of uninvolved muscle groups, as well as cardiovascular endurance, as able</td>
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<td></td>
<td>Perform active or gentle resisted exercises of the hip of the operated lower extremity and resistance exercises of the upper extremities</td>
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<tr>
<td></td>
<td>Proper lower extremity control and alignment with no pain during functional double leg squats</td>
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<tr>
<td></td>
<td>Non-antalgic gait on level surface with full weight bearing and no assistive device, &gt;3mph with equal step length bilaterally 8 point (or greater) improvement on FAAM (ADL portion)</td>
</tr>
<tr>
<td>Phase II Precautions</td>
<td>Avoid over-stressing new scar formation by avoiding any friction over tissue (as per Phase I)</td>
</tr>
<tr>
<td></td>
<td>Avoid post-activity swelling by limiting prolonged weight bearing activity as appropriate. If swelling occurs, manage with rest, ice, elevation and compression (as per Phase I).</td>
</tr>
<tr>
<td></td>
<td>Avoid eccentric loading with any impact activity.</td>
</tr>
<tr>
<td>Phase II Suggested Therapeutic Exercise</td>
<td>Scar massage/mobility and desensitization (once incision is healed). Begin with 3-5 minutes, 1-2x/day and modify as needed.</td>
</tr>
<tr>
<td></td>
<td>Gentle stretching and nerve mobilizations to tissue in involved compartment. Stretch holds for 30-60 seconds, 2-3x/day. Nerve mobilizations begin with 5-8 reps, 3-5x/day; progress number of reps as tolerated. For nerve mobilizations, begin with supine positioning with the lower extremity in a straight-leg raise position; ankle plantarflexion with inversion places tension on the common peroneal tract. (Figure 4a and 4b) Progress by adding hip adduction or internal rotation while doing the straight-leg raise to increase tension on the nervous system. Passive neck flexion will also pull the spinal cord superiorly and places the entire nervous system on a stretch.</td>
</tr>
<tr>
<td></td>
<td>Progress open kinetic chain ankle strengthening. 2-3 sets of 10; progress resistance, sets and reps as tolerated.</td>
</tr>
<tr>
<td></td>
<td>Balance and proprioception exercises: initiate a progression of bilateral to unilateral balance activities first on a level, firm surface, then on a soft/unstable surface, such as dense foam or Bosu ball, and then on a balance board. Begin with eyes open; progress with head turns and eyes closed as able. Goal of 30-60 second holds; 2-3 repetitions, 1-2 times/day.</td>
</tr>
<tr>
<td></td>
<td>Gait drills: begin with sagittal plane and progress to frontal and transverse planes. Examples include forward and backward marching (sagittal plane, Figure 5), sidestepping or side marching (frontal plane), and carioca/grapevine walking (transverse plane). Begin with 10-20 steps, 2-3 repetitions, 1-2 times/day. Progress as tolerated.</td>
</tr>
</tbody>
</table>
Table 2: Continued.

| Phase II Cardiovascular Exercise | Upper body circuit training, upper body ergometer (as per Phase I)  
May begin stationary biking if wound is healed; begin with 5-10 minutes at a low resistance (for example, level 1-2 on a bike with 10 levels), and low cadence (for example 60-80 revolutions per minute). Progress time, cadence, and resistance as able.  
Begin treadmill or track walking if wound is healed; begin with 5-10 minutes at 2-3 mph and progress time and speed as able.  
May swim or water walk if wound is FULLY healed (do not risk infection); begin with 10-15 minutes and progress time and speed as able.  

| Progression Criteria to Phase III | Patient may progress to Phase III if they have met the above stated goals |

Figure 4 A & B. Nerve mobilization exercise in supine. The lower extremity is placed in a straight-leg raise position, nerve gliding is performed by actively and alternately plantarflexing in inversion (A) and dorsiflexing (B) the ankle. Note: ankle plantarflexion with inversion places tension on the common peroneal nerve tract.

Table 2: Continued.

| Phase II Cardiovascular Exercise | UPPER body circuit training, upper body ergometer (as per Phase I)  
May begin stationary biking if wound is healed; begin with 5-10 minutes at a low resistance (for example, level 1-2 on a bike with 10 levels), and low cadence (for example 60-80 revolutions per minute). Progress time, cadence, and resistance as able.  
Begin treadmill or track walking if wound is healed; begin with 5-10 minutes at 2-3 mph and progress time and speed as able.  
May swim or water walk if wound is FULLY healed (do not risk infection); begin with 10-15 minutes and progress time and speed as able.  

| Progression Criteria to Phase III | Patient may progress to Phase III if they have met the above stated goals |

Figure 5. Gait drill involving forward marching.
### Phase III

#### Appointments

Rehabilitation appointments are 1x every 7-10 days on average

#### Rehabilitation Goals

- Prevent post-operative recurrence of symptoms with all activity
- Tolerate 15-30 minutes of continuous aerobic activity without the onset of symptoms/pain
- Reinforce self-monitoring and review signs of recurrence and complications.
- Full 5/5 pain free ankle strength with manual muscle testing of muscles in involved compartment
- Proper lower extremity control and alignment and no pain with single leg functional movements including squats and lunges
- No residual swelling 12-24 hours following all physical activity (including impact exercises)
- No pain 1-2 hours following physical activity (including impact exercises)

#### Precautions

- Avoid friction over scar tissue (as per phase I-II)
- Avoid post-activity swelling (as per phase I-II)
- No strenuous activity until wound is fully healed
- Suggest no running until 6-8 weeks postoperatively (patient should be advised by physical therapist and MD prior to initiation of any running)
- Avoid pain with any exertional activity

#### Suggested Therapeutic Exercise

- Lower extremity stretching and nerve mobilizations as appropriate (per Phase II)
- Lower extremity myofascial stretching/massage and “The Stick” or a foam roller (rolling lower extremities over the roller in long sitting or prone with legs internally rotated, for posterior (Figure 6a) or anterior (Figure 6b) legs) for rolling deep massage to improve flexibility and soft tissue mobility. Begin with 1-3 minutes 1x/day and progress as tolerated.
- Progression of lower extremity closed chain functional strengthening including lunges, step-backs (off of a standard step; Figure 7a and 7b), and single leg squats. Also consider double leg heel rise progressing to single leg heel rise with and without gait drills (such as marching), toe and heel walking. Begin with 2-3 sets of 10 reps, 1 time/day, and progress as tolerated.
- Initiate plyometric exercises (with focus on lower extremity control and alignment at hip, knee, and ankle) at 6 weeks. Begin with 2 feet to 2 feet (jumping; Figure 8a and 8b), progressing from 1 foot to other (leaping) and then 1 foot to same foot (hopping). Focus on proper landing/deceleration mechanics. Begin with 1-2 sets of 10 repetitions. Progress number of repetitions, sets, as well as height or distance as tolerated.

#### Cardiovascular Exercise

- Initiate or progress swimming or water walking if wound is fully healed (as per Phase II)
- Progress walking time and speed (as per Phase II)
- May begin elliptical trainer for 10-15 minutes at low resistance (for example, level 1-2 on an elliptical with 10 levels). Progress time and resistance as able.
- Light jogging can be initiated at 6-8 weeks; initially begin on level surface while avoiding hills and speed work. For runners, consider 5 minute interval training involving walking (for example 1-2 minutes of jogging followed by 3-4 minutes of walking). Progress jog interval times, incline, and speed as appropriate for return to sport/activity goals. For those returning to multi-planar sport, consider progression outlined in Appendix 1.

#### Progression Criteria to Phase IV

Patient may progress to Phase IV if they have met the above stated goals.

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**Table 3: PHASE III: Progression of Strengthening (begin after meeting Phase II criteria, approximately 4-6 weeks following surgery).**

<table>
<thead>
<tr>
<th>Category</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase III Appointments</td>
<td>Rehabilitation appointments are 1x every 7-10 days on average</td>
</tr>
<tr>
<td>Phase III Rehabilitation Goals</td>
<td>Prevent post-operative recurrence of symptoms with all activity</td>
</tr>
<tr>
<td></td>
<td>Tolerate 15-30 minutes of continuous aerobic activity without the onset of symptoms/pain</td>
</tr>
<tr>
<td></td>
<td>Reinforce self-monitoring and review signs of recurrence and complications.</td>
</tr>
<tr>
<td></td>
<td>Full 5/5 pain free ankle strength with manual muscle testing of muscles in involved compartment</td>
</tr>
<tr>
<td></td>
<td>Proper lower extremity control and alignment and no pain with single leg functional movements including squats and lunges</td>
</tr>
<tr>
<td></td>
<td>No residual swelling 12-24 hours following all physical activity (including impact exercises)</td>
</tr>
<tr>
<td></td>
<td>No pain 1-2 hours following physical activity (including impact exercises)</td>
</tr>
<tr>
<td>Phase III Precautions</td>
<td>Avoid friction over scar tissue (as per phase I-II)</td>
</tr>
<tr>
<td></td>
<td>Avoid post-activity swelling (as per phase I-II)</td>
</tr>
<tr>
<td></td>
<td>No strenuous activity until wound is fully healed</td>
</tr>
<tr>
<td></td>
<td>Suggest no running until 6-8 weeks postoperatively (patient should be advised by physical therapist and MD prior to initiation of any running)</td>
</tr>
<tr>
<td></td>
<td>Avoid pain with any exertional activity</td>
</tr>
<tr>
<td>Phase III Suggested Therapeutic Exercise</td>
<td>Lower extremity stretching and nerve mobilizations as appropriate (per Phase II)</td>
</tr>
<tr>
<td></td>
<td>Lower extremity myofascial stretching/massage and “The Stick” or a foam roller (rolling lower extremities over the roller in long sitting or prone with legs internally rotated, for posterior (Figure 6a) or anterior (Figure 6b) legs) for rolling deep massage to improve flexibility and soft tissue mobility. Begin with 1-3 minutes 1x/day and progress as tolerated.</td>
</tr>
<tr>
<td></td>
<td>Progression of lower extremity closed chain functional strengthening including lunges, step-backs (off of a standard step; Figure 7a and 7b), and single leg squats. Also consider double leg heel rise progressing to single leg heel rise with and without gait drills (such as marching), toe and heel walking. Begin with 2-3 sets of 10 reps, 1 time/day, and progress as tolerated.</td>
</tr>
<tr>
<td></td>
<td>Initiate plyometric exercises (with focus on lower extremity control and alignment at hip, knee, and ankle) at 6 weeks. Begin with 2 feet to 2 feet (jumping; Figure 8a and 8b), progressing from 1 foot to other (leaping) and then 1 foot to same foot (hopping). Focus on proper landing/deceleration mechanics. Begin with 1-2 sets of 10 repetitions. Progress number of repetitions, sets, as well as height or distance as tolerated.</td>
</tr>
<tr>
<td>Phase III Cardiovascular Exercise</td>
<td>Initiate or progress swimming or water walking if wound is fully healed (as per Phase II)</td>
</tr>
<tr>
<td></td>
<td>Progress walking time and speed (as per Phase II)</td>
</tr>
<tr>
<td></td>
<td>May begin elliptical trainer for 10-15 minutes at low resistance (for example, level 1-2 on an elliptical with 10 levels). Progress time and resistance as able.</td>
</tr>
<tr>
<td></td>
<td>Light jogging can be initiated at 6-8 weeks; initially begin on level surface while avoiding hills and speed work. For runners, consider 5 minute interval training involving walking (for example 1-2 minutes of jogging followed by 3-4 minutes of walking). Progress jog interval times, incline, and speed as appropriate for return to sport/activity goals. For those returning to multi-planar sport, consider progression outlined in Appendix 1.</td>
</tr>
<tr>
<td>Progression Criteria to Phase IV</td>
<td>Patient may progress to Phase IV if they have met the above stated goals.</td>
</tr>
</tbody>
</table>
Figure 6 A & B. Lower extremity deep massage using a foam roller to improve flexibility and soft tissue mobility for posterior (A) and anterior (B) aspects of the lower leg

Figure 7 A & B. Step-back lower extremity closed chain functional strengthening exercise, frontal plane (A) and sagittal plane (B)
Figure 8 A & B.  

Plyometric exercise: jumping, frontal plane (A) and sagittal plane (B)

### Table 4: PHASE IV: Impact/Sport Training (begin after meeting Phase III criteria, approximately 8-12 weeks following surgery)

<table>
<thead>
<tr>
<th>Category</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase IV</td>
<td></td>
</tr>
<tr>
<td>Appointments</td>
<td>Rehabilitation appointments are 1 time every 2-3 weeks</td>
</tr>
<tr>
<td>Phase IV</td>
<td></td>
</tr>
<tr>
<td>Rehabilitation Goals</td>
<td>Administer FAAM (ADL and sport subscales) prior to discontinuation of therapy. 9 point (or greater) improvement on FAAM (sport subscale portion)</td>
</tr>
<tr>
<td></td>
<td>Proper dynamic neuromuscular control and alignment with eccentric and concentric multi-plane activities (including impact) for return to work/sports, without pain, instability or swelling</td>
</tr>
<tr>
<td></td>
<td>Within 90% of pain free strength (compared to uninvolved side) on leg press (heel raise/PF) or isokinetic biodex testing (PF and DF)</td>
</tr>
<tr>
<td>Phase IV</td>
<td></td>
</tr>
<tr>
<td>Precautions</td>
<td>Avoid pain with any exertional activity</td>
</tr>
<tr>
<td></td>
<td>Avoid post-activity swelling (as per phase 1-III)</td>
</tr>
<tr>
<td>Phase IV</td>
<td></td>
</tr>
<tr>
<td>Suggested Therapeutic Exercise</td>
<td>Biomechanical assessment of specific sport activity with video analysis as needed (running, biking, etc)</td>
</tr>
<tr>
<td></td>
<td>Instruct in proper return to activity progression (incremental running, biking, etc)</td>
</tr>
<tr>
<td></td>
<td>Progressive strengthening exercises using higher stability, and neuromuscular control with increased loads and speeds and combined movement patterns; begin with low velocity, single plane activities and progressing to higher velocity, multi-plane activities. Begin with forward and backward, progress to side-to-side, diagonals and transverse plane movements</td>
</tr>
<tr>
<td></td>
<td>Integrate movements and positions into exercises that simulate functional activities. Sport-specific training beginning with low-intensity simulated movements.</td>
</tr>
<tr>
<td>Phase IV</td>
<td></td>
</tr>
<tr>
<td>Cardiovascular Exercise</td>
<td>Replicate sport or work specific energy demands</td>
</tr>
<tr>
<td>Return To Sport/Work Criteria</td>
<td>Patient may return to sport/work if they have met the above stated goals and have physician and rehabilitation specialist approval. Precautions to reduce the risk of re-injury when returning to sports or high-demand activities as appropriate. If collision/contact sport, may consider protective padding over area of scar tissue.</td>
</tr>
</tbody>
</table>
SUMMARY
Adequate long-term follow-up of outcomes following compartment release for CECS is lacking in the current literature. No specific rehabilitation guidelines following surgical compartment release for lower extremity CECS were found in the literature search utilized by the author of this clinical commentary. Limited time-based rehabilitation guidelines were found, although there was inconsistency in the timelines for treatment, treatment progression, and return to activity/sport. None of the guidelines specifically considered time requirements for tissue healing, demands of eccentric muscle loading, effects of scar tissue formation, and consideration of all tissues (particularly nerve) contained in a compartment. The proposed scientifically-based guidelines for rehab following compartment release presented in this clinical commentary include consideration of tissue healing, muscle loading, scar tissue formation, and consideration of all tissues contained in the involved compartment. Following these proposed guidelines, may reduce risk of recurrence and optimize outcomes following this type of procedure. In addition, it may allow for additional research to be performed that can effectively assess outcomes following this type of procedure. Furthermore, use of these guidelines may allow better understanding regarding why some patients do well following surgical decompression and others fail.

REFERENCES
20. Raikin SM, Rapuri VR, Vitanzo P. Bilateral simultaneous fasciotomy for chronic exertional


**Appendix 1:** Sample running progression for return to multi-planar sport. Property of UW Health Sports Medicine Clinic, used with permission
ABSTRACT

Since the inception of the term *Sports Medicine* Athletic Trainers, Sports Physical Therapists, Paramedics, and Emergency Room Physicians have faced a number of challenges when it comes to providing care to an equipment laden athlete suspected of having a cervical spine or serious head injury. The same equipment that is designed to protect the player may significantly impede the medical team when it comes to diagnosing and treating cervical spine and head injuries. Incorrectly removing the helmet and shoulder pads from a football player with a cervical spine injury, may lead to unwanted motion of the cervical spine during removal. It is the purpose of this article to review the current concepts relating to equipment removal and to introduce a novel system for quick and easy removal of football shoulder pads called the Riddell™RipKord system.

*Key Words:* emergency management, cervical spine injury, equipment removal

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Michael Kordecki is the designer and patent owner for the RipKord System, manufactured by Riddell™.
INTRODUCTION
Since the inception of the term Sports Medicine Athletic Trainers, Sports Physical Therapists, Paramedics, and Emergency Room Physicians have faced a number of challenges when it comes to providing emergency care to an equipment laden athlete suspected of having a cervical spine or serious head injury. The same equipment that is designed to protect the player may significantly impede the medical team when it comes to diagnosing and treating cervical spine and head injuries.1-8 The equipment currently being utilized has undergone substantial design improvements to enhance its protective capacity without any concurrent improvement in the ability to remove the equipment when a potentially catastrophic injury occurs on the field of play. Incorrectly removing the helmet and shoulder pads from a football player with a cervical spine injury, may lead to unwanted motion of the cervical spine during removal.8 Difficulty with removal creates the potential for additional injury to the cervical spine, which could lead to greater possibility of paralysis or increased overall long-term disability of the injured athlete. It is the purpose of this article to review the current concepts relating to equipment removal and to introduce a novel system for quick and easy removal of shoulder pads called the Riddell™RipKord system.

HELMET REMOVAL
Controversy exists about the removal of football helmets when a suspected cervical spine or head injury

Figure 1: Athlete immobilized on spine board. Note that shoulder pads and helmet remain on, as is typical with current protocol for transportation.

Figure 2: Athlete immobilized on spine board with helmet and shoulder pads removed, note easy access for AED and use of cervical collar.
has occurred. A plan for the emergency management of the athlete who is wearing a helmet is critical for those who provide on field coverage. In lieu of full helmet removal, several protocols suggest removal of the facemask in order to gain airway access.\textsuperscript{9, 10} The football helmet can be equipped with quick releases designed to allow removal of the facemask in a timely fashion providing at least partial access to the injured athlete’s airway. However, even with the facemask removed, the ability to manage the airway or use a bag-valve-mask can be an extremely difficult task due to the difficulty opening the athlete’s mouth secondary to the presence of the chin strap. Removing the chin strap could cause unwanted movement of the head inside the helmet. The decision has to be made, whether to leave the helmet and shoulder pads on, or remove them.\textsuperscript{9, 10}

**SPINE BOARDING**

The current emergency management protocol for managing an athlete with a suspected cervical spine or serious head injury dictates that the athlete be placed on the long spine board after being placed in the supine position with the facemask removed from the helmet. A number of techniques for ‘spine boarding’ have been described in the literature including the log-roll, the lift and side, and 6+ person lift. Although not the primary focus of this Clinical Suggestion, it should be noted that until recently the log-roll was taught as the only technique to be used by qualified individuals to place an injured athlete on the spine board.\textsuperscript{1, 11} Del Rossi et al\textsuperscript{11} suggest that the “log-roll” technique is not an effective method for controlling cervical spine motion while placing injured athletes on a long spine board. They go on to suggest that the 6+ person lift is a safer, more effective technique for placing an athlete on a long spine board when attempting to minimize cervical and lumbar spine motion.

**SHOULDER PAD REMOVAL**

Even with improvements regarding methods used to place an injured athlete on the long spine board, medical personnel continue to have many equipment related obstacles to overcome when managing emergent or acute head and neck injuries in football and hockey players. Numerous authors\textsuperscript{1-9, 12-15} have studied the effects of spine motion during the equipment removal process which usually takes place in the emergency department. Recently Swartz et al\textsuperscript{11} concluded “equipment removal is a very complex and difficult task that can result in potentially dangerous cervical spine motion”. The helmet and shoulder pads must be removed as a unit in order to maintain a neutral, stable cervical spine.\textsuperscript{1, 3, 6, 7}
Despite their usefulness in injury prevention to football players, protective shoulder pads serve as a significant obstruction for medical personnel during the critical initial moments of evaluation of an athlete who may have sustained a cervical spine or serious head injury. The presence of shoulder pads can also prevent the use of critical diagnostic and treatment tools, such as radiography or the use of an automated external defibrillator (AED). Please refer back to Figure 2 to see the open access for AED that is accomplished after removal of shoulder pads.

The shoulder pads pose a significant challenge to the medical team’s ability to effectively immobilize the cervical and lumbar spines during the equipment removal process. With the pads in place both the cervical and lumbar spines are too extended, and it is difficult to properly use a cervical collar.

Presently, there are two methods for shoulder pad removal, the levitation technique and the elevated torso technique. During the levitation technique, at least 6 trained medical personnel are needed to levitate or raise the athlete to a position appropriate to remove the shoulder by splitting the front then dropping the pads under the athlete and pulling them to one side as a unit. During this technique, although it is the intent to keep the head and torso stable and immobile, these regions may inadvertently move while attempting to safely remove the shoulder pads.

During the elevated torso technique one rescuer must straddle the athlete’s torso in order to lift the injured player’s torso off the long spine board to an approximate 45 degree angle, while keeping the head and neck stable, and while keeping the athlete’s buttocks and lower extremities on the long spine board. During this maneuver the athlete is flexed at the waist in order to elevate the torso and allow the pads to be dropped under the athlete and removed.
by sliding the pads laterally as a unit. The athlete is then returned to a supine position on the long spine board. This type of lift can be difficult to perform, even under ideal circumstances, especially if the injured athlete is on the spine board and the spine board is on a hospital gurney or stretcher.

**THE RIDDELL™RIPKORD SYSTEM**

The Riddell™RipKord system, a quick release system, developed by a sports physical therapist for removal of the shoulder pads (alone or in combination with a rib belt or lower back pad) is being manufactured by Riddell™, Inc. (Rosemont, IL) (Figures 8,9). The Riddell™RipKord system provides a method for safely and effectively removing football equipment whether on the field or in the Emergency room. With a simple pull of the anteriorly located tab, the system allows for easy separation of the posterior parts of the shoulder pads. Therefore, rather than wait until the athlete is at the hospital, the helmet and shoulder pads can be removed as soon as the athlete is placed on the spine board on the field. This system reduces induced movement to the cervical and lumbar spine while allowing immediate, full access to the athlete’s chest and airway. The removal of the football gear prior to transportation provides immediate access to diagnostic testing once the injured athlete is in the emergency department and allows for diagnostic tests such as radiographs or magnetic resonance imaging (MRI) to be performed quickly.

With the use of the Riddell™RipKord system, removing the shoulder pads and helmet only requires 2-3 trained medical professionals even if the shoulder pads have a lower back pad or rib belt attached, regardless of the size of the athlete. The Riddell™RipKord is operated by cutting the laces or straps in the front of the shoulder pads and then pulling on the tab located at the top of the lace plate. Once the RipKord is pulled out, the right and left halves of the shoulder pads are

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**Figure 8:** The elevated torso technique for shoulder pad removal.

**Figure 9:** Riddell™ RipKord adapted shoulder pads, front view.

**Figure 10:** Riddell™ RipKord adapted shoulder pads, back view. Note the tabs that connect the left and right halves of the pads, the RipKord system allows for separation of the halves at the tabs.
disconnected in the back. The shoulder pads can then be removed by sliding the right and left halves (each in a lateral direction) thus sliding them out from under the athlete, while the athlete remains in the supine position. Pads can be removed quickly without having to elevate the athlete from the long spine board as in the previously described other techniques.

**ADDITIONAL CONSIDERATIONS: USE OF AED, PERFORMANCE OF CPR, CONTROLLING BODY TEMPERATURE, AND USE OF CERVICAL COLLARS**

Currently a football player suspected of having a spine or significant head injury is transported to the trauma center strapped to the spine board with helmet and shoulder pads in place and the facemask removed. In the event of shock or a cardiac emergency during transportation, the paramedic team has the daunting task of trying to remove the athlete's shoulder pads and helmet while in the ambulance, while the ambulance is in motion. In order to do so, the athlete must be unstrapped from the spine board, only to have the equipment wrestled from their body with little or no regard to cervical spine and head position. With the shoulder pads removed prior to transportation, the medical team can apply and use a cervical collar for immobilization and have full unrestricted access to the airway.

Cardiogenic or neurologic shock can occur after a catastrophic event such as a serious head or spine injury. Shock often develops slowly and is not apparent until some time after the original injury. Shock, if untreated will lead to death. In the case the emergency management of a football player with shoulder pads and helmet in place, the use of an AED, performance of CPR, and control of body temperature is extremely difficult. Removing the helmet and shoulder pads immediately after the athlete is placed on the spine board, will provide the medical team full access to the chest and airway, as well as the ability to manage body temperature, which is not possible with the current protocols and equipment design. Utilization of the AED in the instance of ventricular fibrillation or ventricular tachycardia is necessary in the immediate evaluation and treatment on the field, during transportation, and in the hospital emergency room.

Cervical spine immobilization collars are effective at controlling cervical spine motion. As dictated by current protocols (where the shoulder pads and helmet are left on for transportation) cervical immobilization collars are not used during transportation of an athlete with a suspected spine or head injury. Even with the athlete's helmet secured to the spine board, motion can still take place inside the helmet if the chin strap is loose, or if the helmet fit is poor. Cervical collars can not be used when the helmet and shoulder pads are in place due to the lack of clearance between the arches of the shoulder pads and the bottom ridge of the helmet. If the equipment is removed as soon as the athlete is placed on the spine board, as suggested above using the Riddell™RipKord system, a cervical collar can be utilized prior to and during transportation in an ambulance.

As previously mentioned, a significant problem is the difficulty of using diagnostic studies to determine the extent of a cervical or lumbar spine injury with the protective equipment in place. Due to the difficulty during removal and resulting cervical and lumbar motion that may occur, the equipment is often left in place and the medical team attempts to work around the equipment during imaging procedures, often with limited success. It is well documented that an MRI cannot be utilized when diagnosing a spine injury as long as the protective equipment stays in place.
place due to the presence of metal contained within the football equipment.\textsuperscript{12} Even though a plain radiograph is a reasonable tool used for diagnosing spine pathology, cervical spine radiographs have been shown to have limited or no value if the helmet and shoulder pads remain on the athlete\textsuperscript{12, 17, 18} when the radiographs are taken. The density of the plastic and the metal that used in both helmets and shoulder pads obliterates a clear view of the cervical spine in the radiographs. Currently, the medical community relies on the use of Computerized Tomography (CT) to diagnosis spine pathology in an equipment laden athlete. The CT scan has been shown to be an effective tool for describing bony pathologies but has not been found to be reliable for disc or ligamentous injuries of the spine.\textsuperscript{19, 20} Redberg reported that a CT scan could expose a patient to such massive amounts of radiation in a single scan that it could ultimately prove to be fatal.\textsuperscript{21} Additionally, the CT scan exposes the thyroid gland to high doses of radiation, especially when used in the athlete with suspected injury of the cervical spine. The thyroid gland has been determined to be the organ in the body most susceptible to radiation toxicity and use of a CT scan may increase the possibility of the development of cancer at a later date. If an athlete is brought into the Emergency Room with all protective equipment removed, regular radiographs and MRI can be used to determine the path of treatment, avoiding the risk of using a CT scanner as a first line diagnostic tool.

An additional benefit of this release system available through Riddell\textsuperscript{™} is that the shoulder pads are specifically designed to be reassembled after they are disconnected using the Riddell\textsuperscript{™}RipKord system. In the event a player needs to have the pads removed emergently, the pads will not be damaged. In most cases the shoulder pads can be put back together in under five minutes without any resulting damage. The only item which will need to be replaced is the laces or fasteners from the front of the pads if they are cut during the removal process.

**CONCLUSIONS**

The Riddell\textsuperscript{™}RipKord system will provide the medical community the ability to change the current equipment removal protocols. These protocols were established based on the existing design of the helmet and shoulder pads and shoulder pad/rib belt/lower back pad combination. By utilizing the Riddell\textsuperscript{™}RipKord release system, the medical team will be able to remove protective equipment, namely the helmet and shoulder pads, in a safe, effective, and timely manner without ever having to lift the athlete once they are placed on the spine board. In doing so, all involved medical professionals would have full access to the airway and chest, the ability to maintain appropriate body temperature, and could properly use a cervical stabilization collar. Immediate, effective diagnosis and treatment will not to be delayed due the difficult task of removing the protective equipment as it is currently designed. This release system has potential applications at all levels of play, during which athletes use protective equipment including professional, collegiate, high school, and grammar school athletes.

**REFERENCES**


ABSTRACT

**Background:** Female athletes continue to injure their anterior cruciate ligaments at a greater rate than males in comparable sports. During landing activities, females exhibit several different kinematic and kinetic traits when compared to their male counterparts including decreased knee flexion angles as well as decreased lower extremity (LE) strength. While open kinetic chain strength measures have not been related to landing kinematics, given the closer replication of movement patterns that occur during closed kinetic chain (CKC) activity, it is possible that lower extremity strength if measured in this fashion will be related to landing kinematics.

**Purpose:** To determine if unilateral isometric CKC lower extremity (LE) strength was related to sagittal plane tibiofemoral kinematics during a single leg landing task in competitive female athletes. We hypothesized females who demonstrated lesser CKC LE strength would exhibit decreased sagittal plane angles during landing.

**Methods:** 20 competitive female athletes (age = 16.0 ± 1.8 yrs; height = 166.5 ± 8.3 cm; weight = 59.7 ± 10.2 kg) completed CKC LE strength testing followed by 5 unilateral drop landings on the dominant LE during one test session at an outpatient physical therapy clinic. Closed kinetic chain LE strength was measured on a computerized leg press with an integrated load cell while sagittal plane tibiofemoral kinematics were quantified with an electrogoniometer.

**Results:** No significant relationships between absolute or normalized isometric CKC strength and sagittal plane landing kinematics were identified.

**Conclusions:** Closed kinetic chain lower extremity isometric strength tested at 25 degrees of knee flexion is not related to sagittal plane landing kinematics in adolescent competitive female athletes.

**Levels of Evidence:** Analytic, Observational

**Key Words:** ACL, Closed Kinetic Chain, Female, Kinematics, Strength

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INTRODUCTION
Anterior cruciate ligament (ACL) injury continues to occur at an alarming rate in female athletes.1 The vast majority of ACL injuries occur during a non-contact or non-collision mechanism.2,3 Common mechanisms of injury include cutting, pivoting, or while landing from a jump.4,5 Many risk factors to explain the gender disparity have been proposed.6 Arguably the most compelling sex specific biomechanical risk factor heightening injury risk is faulty lower extremity (LE) kinematics during landing. Researchers consistently report that females exhibit lesser knee flexion when landing from a jump.7,8 The ramifications of a more extended knee posture during landing include decreased hamstring activity,10-13 increased quadriceps activity,10 increased anterior tibial translation11-12,14-15 and increased vertical ground reaction forces.9,16 Furthermore, less total knee joint excursion occurs throughout the maneuver resulting in a shorter time period for the dissipation of loads at the joint.17 Each of these alterations is thought to heighten ACL injury risk.15,16,21 The reasons females exhibit lesser knee flexion angles during landing is unclear. Investigators have identified that female athletes are more quadriceps dominant when compared to their male counterparts.6 Given the action of the quadriceps, dominance of this muscle group would encourage a more extended knee posture during landing. Likewise, it is plausible that female athletes rely more on bony geometry and passive capsuloligamentous restraints to compensate for deficiencies in LE strength.

Traditional LE strength measures quantified in an open kinetic chain (OKC) have been poorly associated with landing kinematics.22-24 The ability to generate strength in a closed kinetic chain (CKC), similar to a squat maneuver, more closely represents LE kinematics during a landing task compared to OKC strength measures. Hence strength quantified in a CKC may be related to landing kinematics in female athletes. Other authors have identified significant relationships between CKC strength and performance on functional tasks including a single leg hop, vertical jump and a speed/agility test.25 The authors of the current study, however, were unable to identify previous work specifically exploring the relationship between CKC strength and landing kinematics. Therefore, the purpose of this study was to determine if LE strength as measured isometrically in a CKC via a squat maneuver was related to sagittal plane knee kinematics during a landing task in competitive female athletes. We hypothesized that females who demonstrated lesser LE CKC strength would exhibit decreased sagittal plane angles during landing.

METHODS
Twenty competitive female athletes (age = 16.0 ± 1.8 yrs; height = 166.5 ± 8.3 cm; weight = 59.7 ± 10.2 kg) from the sports of soccer (n = 16), basketball (n = 2) and volleyball (n = 2) were recruited for participation in this University IRB approved study. All enrolled soccer players competed at the cup level signifying elite status for their age. Inclusion criteria consisted of no history of surgery or a LE injury on the dominant side within the last six months which necessitated the use of crutches for more than one day. Subjects were excluded from the study if they were ACL deficient, had undergone ACL reconstruction, or had previously suffered other significant LE trauma (e.g. fracture, patellar dislocation, torn meniscus). Likewise, subjects were excluded if they were unable to perform the drop landing task or CKC strength assessment without pain. None of the subjects in this study wore foot orthotics on a daily basis or for participation in sport activity.

Identical procedures including informed consent were followed for each participant. All data was collected on the dominant LE during a single session at an outpatient physical therapy clinic. First, each subject's height and weight were measured using a mechanical beam scale (Pelstar LLC; Alsip, IL). Then, leg dominance was determined by the LE on which the subject landed from a 40 cm wood box on two out of three trials.26 Next, the primary investigator performed a physical examination of the subject's dominant lower extremity. The primary investigator has 20 years of experience in an orthopedic, sports medicine rehabilitation setting and has attained ABPTS certification in both the areas of orthopedic and sports physical therapy. The exam consisted of inspection, range of motion assessment, manual muscle testing of the quadriceps and hamstrings and tests for ligamentous and patellar instability. All
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Subjects demonstrated no swelling, full range of motion with normal end feels, strong and painless manual muscle tests, and negative ligamentous tests including the Lachmann and patellar apprehension tests. After the screening, subjects donned their sneakers and performed a 5 minute warm-up on a recumbent bicycle (Ufit Technology; Woodinville, WA) at a self-selected pace. Next, subjects performed practice trials of the drop landing task. The subject stepped onto a box 40 cm in height, placed hands on iliac crests, feet shoulder width apart and toes aligned just over the edge of the platform. The subject was then instructed to lean forward, fall off the platform, and land on her dominant lower extremity. Placing hands on iliac crests minimized the influence of upper extremity motion on landing kinematics. Subjects were instructed to maintain single limb balance until cued by the investigator to place the opposite LE on the floor. Each subject was allowed as many practice trials as necessary to become adept at the task. Subjects usually required only two to three trials to become comfortable with the task. Next, an electrogoniometer (EG) (Model SG-150; Biometrics Ltd; Gwent, UK) was centered over the lateral joint line of the tibiofemoral joint. The proximal block of the EG was aligned with the greater trochanter and the distal block with the lateral malleolus. The EG was secured to the lateral aspect of the knee using double sided tape (Scotch; 3M, St. Paul, MN) and subsequently circumferentially wrapped with 2¾” pre-wrap (Cramer Products Inc.; Gardner, KS). Once the EG was secured, the subject was asked to stand with her knee straight (0°) at which time the EG was zeroed in the sagittal plane. Verification of the zero degree reference angle was made both visually and goniometrically by the same investigator. Subjects were then asked to bend and straighten their knee so that data from the EG could be visually confirmed on a laptop personal computer (PC) (Dell; Austin, TX).

Subjects were then visually and verbally oriented to the computerized leg press (CDM Sport; Fort Worth, TX). To further familiarize the subject with the leg press and control for a learning effect and potentially reduce fatigue, subjects were asked to use their non-dominant LE to push against the foot plate of the leg press for two sub-maximal repetitions. Once familiar with its operation, subjects assumed a standardized position on the leg press (Figure 1). Specifically foot position was adjusted so the subject's tibial crest was horizontal to the floor and the hip was placed in neutral alignment with respect to the frontal plane. The sled of the leg press was adjusted so the knee was flexed to 25°. Twenty five degrees of knee flexion was chosen to quantify lower extremity strength as this is representative of the angle at which many females land from a jump and the approximate angle at which ACL injuries occur. Upper extremity position was standardized by having each subject grasp the handles on the leg press. Once the subject was properly aligned, the leg press was locked. Locking the leg press ensured the subject maintained the standardized position during testing. Subjects pushed with their foot against the plate of the leg press five times. Each repetition was held for 5 seconds with a 25 second rest between each repetition thereby providing a 1:5 work rest ratio. Subjects performed the first and second repetition at a perceived effort of 50 and 75% respectively. The remaining three repetitions were each performed at 100% effort. Dependent measures derived from the three repetitions performed at 100% included maximal force and average force. Force was sensed by a load cell that was integrated into the leg press by the manufacturer. The load cell was tested at the manufacturer for repeatability, zero balance, creep, non-linearity, and hysteresis and
was collected using a trigger sweep method of one second duration (300 milliseconds [ms] pre-contact and 700 ms post-contact) initiated by the foot switch. The EG sampled at a rate of 2000 hertz and has been shown to be highly reliable (ICC\(_{[3,k]}\) = 0.995) under test-retest conditions and valid (ICC\(_{[3,k]}\) = 0.991) when compared to three-dimensional motion analysis when assessing sagittal plane knee kinematics during landing activities. A published systematic review of the literature for use of the EG to quantify tibiofemoral kinematics further substantiated these findings. Upon landing, subjects were asked to 'stick the landing' and maintain single limb balance for one second after each trial. Failure to meet these criteria resulted in negation and a repeat of the trial. After the fifth successful trial, the instrumentation was removed from the subject and the experiment was complete. With only a few exceptions subjects successfully completed each trial. Of these exceptions, subjects needed to complete only an additional one to two trials for a total of five acceptable trials.

**Data reduction & statistical analysis**

For the leg press, a mean from the last three repetitions for each variable (maximum force, and average force) was used for data analysis. Two additional variables were created by normalizing force to body weight (maximum force/body weight; average force/body weight). Kinematic trials were signal averaged using the software acquisition system. Once signal averaged, an event buffer 100 ms in duration starting at initial contact was established for each subject. A maximum of 100 ms was established as ACL injury has been reported to occur within this window. Within this temporal envelope, sagittal plane knee flexion angles at initial contact and 100 ms were identified (Figure 3). Additionally, the rate of excursion (degrees/second) was calculated by dividing knee excursion by the time difference between knee flexion at 100 ms and initial contact:

\[
\text{Knee Flexion}_{(100 \text{ ms})} - \text{Knee Flexion}_{(\text{Initial Contact})}
\]

\[
\text{Time}_{(100 \text{ ms})} - \text{Time}_{(\text{Initial Contact})}
\]

Pearson correlation coefficients were calculated with a statistical software package (SPSS Version 17.0; Chicago, IL). Alpha levels were established a-priori at \(P < 0.05\).
RESULTS

Descriptive measures of force and kinematic data appear in Table 1. Pearson correlation coefficients exhibiting the relationship between force and kinematic data appear in Table 2. No significant relationships between maximum force, average force or force normalized to body weight and kinematic data were evident.

DISCUSSION

The primary finding of our study was absolute isometric force and isometric force normalized to body weight quantified in a CKC with the knee in slight flexion were not related to sagittal plane knee kinematics during landing in adolescent female athletes. We theorized that females with lesser CKC sagittal plane LE strength would exhibit lesser knee flexion angles in an attempt to compensate for muscular deficiencies by relying on bony geometry and passive ligamentous supports. While some authors have identified a relationship between isokinetic and isometric LE strength and frontal plane knee angles during a single leg squat or step down maneuver respectively, our findings are in agreement with other investigators who have failed to identify an association between LE strength and sagittal plane landing kinematics. Shultz et al examined several neuromuscular thigh parameters including OKC isometric quadriceps and hamstrings strength and electromyographic (EMG) activity of the quadriceps and hamstrings to determine if these variables were predictive of sagittal plane landing kinematics. The investigators however reported very little of the variance during a landing task was explained by the predictor variables of strength and EMG. The biggest difference between this work and the current study

<table>
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<td>Normalized Peak Force (N/kg)</td>
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<td>Sagittal Plane Knee Angle @ Initial Contact (degrees)</td>
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<td>Sagittal Plane Knee Angle @ 100 ms (degrees)</td>
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<td>Rate of Excursion (degrees/second)</td>
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was that Shultz et al quantified isometric strength in an OKC. While an OKC assessment of strength allows for an isolated assessment of muscle groups, muscle groups operate synergistically during tasks such as landing. Though a significant relationship was not apparent, the authors of the current study theorized that if strength were tested in a manner that more closely represented the functional task of interest, a relationship between these two variables would be elucidated. In other work, Mizner et al reported that muscle strength was not predictive of alterations in lower extremity landing mechanics following an instructional session intended to improve landing kinematics and kinetics. Likewise, despite observable increases in force production, Herman et al. noted no change in LE kinematics in female athletes during a stop-jump task following nine weeks of LE strengthening. Collectively, the results of the current study and current literature suggest factors other than strength (e.g. kinematics at other joints or neuromuscular control) may explain the LE kinematic patterns observed in female athletes during landing.

Trunk kinematics have been associated with sagittal plane hip and knee kinematics. Specifically, increased trunk flexion angles are related to increased hip and knee flexion angles during landing. As females tend to demonstrate a more erect trunk posture during landing it is possible that trunk position encourages a decreased sagittal plane knee angle during landing. Why female athletes may adopt a more erect trunk position during landing when compared to males is unknown. Given the function of the gluteus maximus as a trunk stabilizer and decelerator of femoral medial rotation, decreased power of this core muscle may partially explain not only a more erect trunk position but also the characteristic collapse of the femurs into medial rotation following landing. Supporting this premise, anecdotally, it is recognized that individuals with substantial gluteus maximus weakness commonly exhibit a gait deviation known as the ‘gluteus maximus lurch’. The gluteus maximus lurch occurs when the trunk quickly moves into excessive extension at heel strike. This gait deviation moves the center of mass posterior to the hip joint thereby minimizing the need for hip extensor activation. Other work has identified females exhibit less gluteus maximus muscle activity when compared to males during a landing task. Additional studies comparing gluteus maximus power production between genders and its relationship to landing kinematics is necessary.

As suggested, the ability to generate force rapidly (muscular power) may be related to tibiofemoral landing kinematics. The authors were unable to identify any studies that have examined this notion. It is unknown if time to peak torque of the hip or knee musculature as investigated either in a closed or open kinetic chain is related to sagittal plane landing mechanics. If related, this may serve as a feasible screening tool to identify female athletes who would benefit from an intervention program aimed at improving muscular power and hence LE landing kinematics. Additional study in this regard is required.

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<th>KA&lt;sub&gt;1C&lt;/sub&gt;</th>
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</tr>
<tr>
<td>Normalized Peak Force</td>
<td>r = -0.03</td>
<td>r = -0.02</td>
<td>r = 0.14</td>
</tr>
<tr>
<td></td>
<td>P = 0.89</td>
<td>P = 0.92</td>
<td>P = 0.55</td>
</tr>
<tr>
<td>Normalized Average Force</td>
<td>r = -0.004</td>
<td>r = -0.005</td>
<td>r = 0.11</td>
</tr>
<tr>
<td></td>
<td>P = 0.98</td>
<td>P = 0.98</td>
<td>P = 0.63</td>
</tr>
</tbody>
</table>
what occurs is an eccentric, not isometric, contraction of the lower extremity musculature. Perhaps sagittal plane landing kinematics would be related to a CKC eccentric measure of force within an arc of motion that is comparable to that experienced by female athletes during landing. The unilateral drop landing task employed in this study is arguably not representative of what occurs on the field of play for many athletes. Athletes rarely if ever land and remain stationary. Whether the results would have been the same or not during a countermovement or drop vertical jump is unknown and requires further study.

Though a CKC assessment of muscle strength may be more representative of the manner in which muscle groups work together during function, it is less clear as to the relative contribution of each muscle group as it relates to the total force production during the strength test. As the methods of this study did not include the acquisition of electromyographic data, it cannot be stated with certainty which muscle groups were specifically tested with the CKC strength test. Based on the strength measure, it was the assumption of the authors that the muscle groups primarily responsible for producing the force included the single joint hip extensors, knee extensors, and ankle plantarflexors. Likewise, it is recognized that other muscle groups worked synergistically throughout the kinematic chain to decelerate as well as provide stabilization in the frontal and transverse planes during the landing task.

CONCLUSIONS

Unilateral lower extremity closed kinetic chain isometric strength (absolute or normalized to body weight) tested at 25° of knee flexion is not related to sagittal plane knee kinematics tested at 25° of knee flexion is not related to sagittal plane knee kinematics during a single-limb drop landing in adolescent female athletes.

REFERENCES


ABSTRACT

Background: Power lifting places the shoulder complex at risk for injury. Microfracture is a relatively new procedure for chondral defects of the glenohumeral joint and is not well described in the literature.

Objectives: The purpose of this case report is to describe the post-operative rehabilitation used with a power lifter who underwent a microfracture procedure to address glenoid and humeral chondral defects, debridement of type I superior labral anterior-posterior lesion, and a subacromial decompression.

Case Description: The patient was a 46 year-old male who was evaluated nine weeks status-post arthroscopic microfracture procedure for glenoid and humeral chondral defects, debridement of superior labral anterior-posterior (SLAP) lesion, and subacromial decompression. Rehabilitation consisted of postural education, manual therapy, rotator cuff and scapular strengthening, dynamic stabilization, weightbearing exercises, and weight training over nine weeks (24 sessions). Lifting modifications were addressed.

Outcomes: Results of the QuickDASH indicate that activities of daily living (ADLs), work, and sports modules all improved significantly, and the patient was able to return to recreational power lifting with limited discomfort or restrictions.

Discussion: A structured post-operative physical therapy treatment program allowed this patient to return to recreational power lifting while restoring independent function for work-related activities and ADLs.

Key Words: articular cartilage, microfracture, rehabilitation, shoulder
INTRODUCTION
Power lifting is recognized both nationally and internationally as a highly competitive sport where participants attempt to reach the highest one repetition maximum in a series of lifts including the deadlift, squat, and bench press. Athletes compete in classifications separated by age, weight, and gender. Current International Powerlifting Federation (IPF) men’s records in the bench press, squat, and deadlifts surpass the lifter's body mass by three times, five times, and five times, respectively. These extremely high loads may place the lifter at risk for a host of injuries. Power lifting has been associated with more than 1 injury per year or 2.6-4 injuries per 1,000 hours of training. Not surprisingly, the most frequently injured body part in power lifters is the shoulder. Raske and Norlin found that 93% of shoulder injuries in power lifters lasted more than one month, suggesting these injuries commonly result in prolonged periods away from sport.

The term superior labral anterior-posterior (SLAP) lesion was coined in the early 1990s by Snyder. He categorized these lesions into four types based on involvement of the glenoid labrum and the tendon of the long head of the biceps. Type I lesions are classified as an intact labrum and biceps tendon with fraying of the superior labrum. This type of lesion is commonly degenerative, seen in patients that are middle-aged and elderly, and may or may not be symptomatic. Type I SLAP lesions may be treated with arthroscopic debridement, although this technique has not been shown to be effective in the long term.

Arthroscopic subacromial decompression was first documented by Ellman. He stated that this procedure had the advantage over open decompression first described by Neer in that it spares the disruption and reattachment of the deltoid insertion. In the arthroscopic procedure, the coracoacromial ligament is released, the anterior acromion is resurfaced, osteophytic changes removed, and involved bursae are debrided. Arthroscopic procedures have primarily been used for subacromial impingement syndrome, partial tears of the supraspinatus tendon, and osteoarthritic changes seen in the acromioclavicular joint. Good to excellent results in function, return to work, pain, and ROM have been reported in 75-93% of subjects for those undergoing subacromial decompression for partial-thickness tears and impingement syndrome between the ages of 17 and the mid-60s.

Articular cartilage defects can occur as a direct result from high impact loading, acute trauma, or repetitive compressive/torsional/shear loads placed on cartilaginous tissue, all of which place the athlete at risk for injury. Brittberg & Winalski have described the International Cartilage Repair Society's method of evaluating cartilage defects. These deficits are classified based on the depth and location of the area damaged, as shown in Table 1. This method has been most widely used in classifying chondral defects. Athletes at risk for glenohumeral cartilage damage are those involved with overhead activity, including weight lifters.

Articular cartilage defects rarely heal spontaneously regardless of whether acute, chronic, or degenerative. The limited ability to heal is due to the avascular nature of cartilage and a lack of both chondrocyte division and migration to the injured site throughout the stages of healing. The articular cartilage lesion often leaves individuals with joint effusion, activity-related-pain, and reduced quality of life, and with regard to the athlete, decreased or inability to participate in sports. For the past 30 years, total shoulder arthroplasty and debridement techniques have been the treatment of choice for symptomatic articular deficits in the shoulder complex. Unfortunately, these techniques rarely result in the athlete returning to sport, even at a recreational level.

Cartilage restoration procedures that have emerged over the past two decades, along with an enhanced understanding of the structure and function of cartilage, have improved outcomes for the athlete.
cartilage, has led to changes in surgical intervention for articular defects. These techniques attempt to retard the progression of the defect, relieve pain, maximize function, and return individuals to sport, in many cases at the professional level. One popular surgical technique that has recently been supported in the literature for the lower extremity, particularly in the tibiofemoral and patellofemoral joint, is the microfracture procedure. The goal of the microfracture procedure is the perforation of the subchondral bone in order to induce an associated bleeding response. This allows for the release of marrow elements including undifferentiated mesenchymal stem cells, fibroblasts, growth factors, and a host of inflammatory and chemotactic factors necessary for attempted repair and remodeling of the damaged area. A fibrin clot fills the breeched surface that provides an environment for differentiation into hyaline-like cells and stable tissue. This operative procedure has been performed in the hip, tibiofemoral and patellofemoral, and talocrural joints.

The advantages of microfracture are that it is a relatively safe, straightforward procedure with low associated comorbidity, and should the procedure fail, other options can be implemented. The main disadvantage is that the resultant cartilage is hybrid of hyaline and fibrocartilage. Fibrocartilage has been shown to have inferior mechanical properties when compared to hyaline cartilage, in that it is less stiff and does not resist compression and shear loads as well. This may place the rejuvenated cartilage at risk for future breakdown. Various percentages of native hyaline and fibrocartilage have been found in both animal and human models at 12-72 months postoperatively in the tibiofemoral, glenohumeral, and carpal joint surfaces.

Some authors have advocated for a period of postoperative non-weightbearing for lesions that have been treated within the tibiofemoral/patellofemoral, and talocrural joints. Others suggest partial weightbearing for the hip and tibiofemoral/patellofemoral joints for the first four to eight weeks post-operatively. This period of protective weight bearing is prescribed in order to protect the differentiating cartilage tissue. During this period, continuous passive motion (CPM) is typically used in the tibiofemoral, hip, and glenohumeral joints in order to enhance nutrient and metabolic activity in the articular cartilage and hypothetically push undifferentiated cells to become hyaline-like in nature. However, no functional differences were found between subjects who did or did not use CPM in smaller lesions (less than 2 cm²) in the knee.

For patients who undergo the microfracture procedure for lesions of the tibiofemoral/patellofemoral, hip, and talocrural joints most authors advocate for a course of intensive physical therapy with a subsequent return to sport after four to six months. Unfortunately, there is no guarantee of return to prior level of performance. Mithoefer et al found that only 44% of subjects with tibiofemoral chondral defects returned to high-impact, pivoting sports such as football, soccer, basketball, skiing, tennis, and squash. Perhaps return to sport was initiated too soon, as Steadman et al report that maximum function is often not demonstrated until two to three years post-operatively. Subjects have been shown to return to recreational activity, such as tennis or jogging five days per week, and have sustained that level of participation at 4.2 to 11.3 year average follow-up. Individuals older than age 40 and those with lesions in the lower extremity of greater size than 2 cm² have demonstrated poor outcomes. Cartilage defects of greater than 12 months in duration have also been implicated as a contributor to poorer outcomes, although conflicting evidence exists.

In the glenohumeral joint, there is a paucity of published literature with regards to the use of microfracture technique for treatment of chondral defects. Well-defined rehabilitative protocols following microfracture procedure of this joint are limited. In a case series of five subjects, Siebold et al reported that after three weeks usage of a CPM, subjects were progressed to passive and active ROM until full range of motion was achieved, upon which a rotator cuff strengthening program was initiated. All subjects noted positive results in ADLs, range of motion (ROM), and pain improvement. One high level swimmer was able to return to recreational swimming. However, a periosteal flap was used in addition to the microfracture procedure for the treatment of that athlete. In those with microfracture and periosteal transplantation,
McCarthy and Cole\textsuperscript{31} noted that after six weeks of 600 pendulum exercises performed daily, patients are allowed to progress to AROM and are cleared for unrestricted activity at six months post-operatively.

The purpose of this case report is to describe the post-operative rehabilitation program that was individually designed for a former power lifter who underwent arthroscopy for a microfracture procedure to address glenoid and humeral chondral defects, concurrent with debridement of a SLAP lesion, and a subacromial decompression. The University of Illinois at Chicago Institutional Review Board approved of this study, and informed consent was obtained from the patient.

**CASE DESCRIPTION**

The patient was a 46-year-old, right hand dominant, Caucasian, mesomorphic male, 1.89 meters (74 inches) tall and weighing 151 kilograms (332 pounds). Approximately nine months prior to physical therapy initial evaluation, the patient was deadlifting 181.8 kilograms when he noted a diffuse yet intense pain in his right shoulder region. He continued to weight train for the next seven months, until the pain became unbearable. He decided to follow-up with his physician. Radiographs demonstrated a minimal degree of osteoarthritis in the glenohumeral joint and moderate degree of osteoarthritis in the acromioclavicular joint. Magnetic resonance imaging (MRI) revealed both a glenoid and a humeral cartilage lesion. His physician recommended arthroscopic evaluation and treatment. Arthroscopic surgery revealed a grade IV chondral lesions on the humeral head (Figure 1) and articulating surface of the superior glenoid rim (Figure 2), both of which were 2-3 cm in diameter, accompanied by a type I SLAP lesion. Microfracture procedure (Figure 3) was performed to both articulating surfaces of the glenohumeral joint, along with debridement of SLAP lesion and a subacromial decompression, the latter to ensure clearance of the subacromial space. His initial physical therapy visit occurred at the beginning of the ninth week post-arthroscopy.
INITIAL EXAMINATION

On initial physical therapy examination, the patient presented with forward shoulders bilaterally, downwardly rotated scapulae (right greater than left) and minimal levoscoliosis and kyphosis in the thoracic region. Atrophy was noted throughout the right shoulder musculature, including the trapezius, deltoid, supraspinatus, external rotators, latissimus dorsi, and pectoralis major, and the musculature of the upper brachium, including the biceps and triceps. The surgical sites were well healed without loss of sensation. Sensation to light touch was intact throughout the rest of the upper extremities.

ROM examination of the cervical spine, elbow, forearm, wrist and hand revealed no significant deficits. Table 3 denotes ROM values for the shoulder complex at initial examination and discharge. This patient was limited primarily by pain with all active and passive right shoulder movements. He was unable to don/doff a shirt with his right arm, nor was he able to reach behind his head or back.

Joint mobility examination revealed hypomobility of the sternoclavicular, acromioclavicular, and scapulothoracic joints, thereby diminishing scapular upward rotation bilaterally, although greater on the surgical side. Glenohumeral joint examination exhibited deficits in inferior and posterior translation without pain.

Force generation capacity was severely limited, and therefore, manual muscle testing (MMT) for the shoulder complex was not assessed at initial examination.

At initial examination, the patient noted functional difficulty conducting his work-related activities as a gym owner, such as moving and cleaning weights. Because most of his destinations were within walking distance, he did not report driving as a limitation. Household activities, such as cleaning dishes, floors, and rugs were difficult to complete.

This patient's past medical history included right infraspinatus, supraspinatus, and pectoralis major partial-thickness muscle tears while conducting a bench press approximately six years prior. This injury was treated conservatively with a positive outcome, and the patient decided to discontinue competitive lifting, but continued to train recreationally. He noted that his ROM and strength were worse on the right side after this injury. Subjective reports of his maximum lifts prior to his present injury as well as those achieved post-operatively are described in Table 2. The patient stated that he no longer desired to reach his lifting maximums for fear of damage to his body. His goal was to continue lifting at least 50% of his previous maximum lifts.

<table>
<thead>
<tr>
<th>Lifts Type</th>
<th>Max Prior to Injury</th>
<th>Max Two Years Post-Operatorally</th>
</tr>
</thead>
<tbody>
<tr>
<td>Squat</td>
<td>530 lbs. X10</td>
<td>400 lbs. 4X15</td>
</tr>
<tr>
<td>Deadlift</td>
<td>600 lbs. X1</td>
<td>365 lbs. 4X15</td>
</tr>
<tr>
<td>Bench Press</td>
<td>240 lbs. X2</td>
<td>150 lbs. 4X15</td>
</tr>
</tbody>
</table>

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Intervention
Note: Please refer to Appendix 1 for all details of the three phases of intervention.

Phase I: Protective PROM Phase- Weeks 0-8 Post-operatively
For the first six weeks post-operatively, prior to physical therapy consultation, the patient was issued a CPM machine set at 90 degrees of abduction in the scapular plane and 90 degrees of external rotation by his physician. He used this daily for six hours. For the following two weeks, the patient was allowed to conduct self-PROM into flexion and scapular plane abduction in the supine position as tolerated, per physician instruction. He was then referred to physical therapy for therapeutic management.

Phase II: AROM and Strengthening Phase- Weeks 9-14 Post-operatively
During the first six weeks of physical therapy (weeks 9-14 post-operatively), the treatment plan was designed to address postural dysfunction, normalize passive and active ROM on both sides, and strengthen the periscapular muscles, rotator cuff, and remaining limb musculature bilaterally. During week 9, the patient was educated regarding forward shoulder posture and how it has been linked to shoulder complex dysfunction and pain. Further, because thoracic position has been shown to have effects on shoulder ROM, kinematics, and strength, the patient was educated to avoid thoracic kyphosis or slumped posture. To address pain, grade I-II joint distraction was performed at the glenohumeral joint for pain modulation according to Kaltenborn. Pain-free right glenohumeral PROM was administered at every treatment session to enhance or maintain available ROM and nourish rejuvenating cartilaginous tissue.

Grip strength testing revealed 139 pounds on the right, as compared to 159 pounds on the left, measured via hand-held dynamometer.

The QuickDASH was used as the primary self-reported functional outcome measure. The QuickDASH, developed from the original 30-item Disabilities of Arm, Shoulder, and Hand (DASH) questionnaire, is an 11-item, self-administered questionnaire for upper extremity function and disability. Scores for each individual item range from 1 to 5, 1 being no difficulty, 5 being unable. The QuickDASH also has an optional five question module for both work and sports that are scored separately. For scoring, a sum of the responses is divided by the number of responses, subtracting one, and multiplying by 25 for all three modules separately. Scores range from 0 to 100, 0 indicating no disability. When compared to the 30-item DASH, Beaton et al reported a Pearson’s product-moment coefficient of correlation of .97 (Pearson’s r), with test-retest reliability of .94, and similar construct validity to the DASH. The advantages of the QuickDASH are its simplicity and ease of use.

QuickDASH scores were assessed prior to surgery and post-operatively. Table 4 presents the patient’s QuickDASH scores, with the 11-item ADL measure worsening post-operatively from 40.9 to 81.8. The work module also increased from 56.25 to 75, while the sports module remained unchanged at 100. Given that the intrarater reliability coefficient is .94 with standard deviation of 26.2 points, the calculated standard error of measurement (SEM) of 1 standard deviation is 12.8 at a 95% confidence interval (CI), indicating that he was significantly worse at this point after surgery compared to pre-operative function.

**Table 4. QuickDASH scores**

<table>
<thead>
<tr>
<th>QuickDASH Scores</th>
<th>Pre-Surgical Evaluation</th>
<th>Initial Evaluation</th>
<th>Discharge</th>
<th>2 year post-operatively</th>
</tr>
</thead>
<tbody>
<tr>
<td>11-item ADL</td>
<td>40.9</td>
<td>81.8</td>
<td>15.9</td>
<td>4.5</td>
</tr>
<tr>
<td>Work Module</td>
<td>56.25</td>
<td>75</td>
<td>25</td>
<td>6.25</td>
</tr>
<tr>
<td>Sports Module</td>
<td>100</td>
<td>100</td>
<td>75</td>
<td>25</td>
</tr>
</tbody>
</table>

*Note: Higher scores indicate greater disability.*
This time frame was promoted throughout all glenohumeral rotator cuff strengthening sessions to build muscular endurance, because muscle fatigue has been associated with faulty neuromuscular control.39-40 Standing bicep curls and tricep extensions (Figure 4) were progressed accordingly throughout physical therapy sessions. Forearm, wrist, and hand gripping exercises were also utilized throughout treatment sessions.

During this phase, the patient was allowed to begin squats and deadlifts with no external resistance in order to avoid significant atrophy of his lower extremities. Once the patient achieved supine glenohumeral AROM of flexion past 90 degrees, serratus anterior punches were added without external resistance. Resistance was progressed as the patient’s strength increased.

During week 10, grade II-III mobilizations with both distraction and inferior/posterior glides were administered to address both pain and mobility,37 sternoclavicular joint mobilizations, grade III-IV in a caudal direction, were conducted to improve scapular mobility.37 PROM into straight plane abduction and standing AAROM and AROM glenohumeral flexion and scapular plane abduction were added. Because the patient’s girth did not allow for serratus anterior activity to be monitored with palpation while performing elevation, he was given verbal cues to utilize his serratus anterior while the primary author mobilized his scapula into upward rotation as needed throughout treatment, similar to the scapular assistance test described by Rabin et al.39 Inadequate scapulothoracic upward rotation has been linked to impingement.40 Standing rows with theraband were added to improve scapular strength.

At week 11, grade III-IV joint mobilizations of the glenohumeral joint were added to progress mobility.37 PROM into ER/IR at 90 degrees abduction was conducted. Isotonics began in the order of scaption, flexion, and abduction (Figure 5) to 90 degrees of elevation. Thirty second rest breaks between sets was issued in order to promote training of muscular endurance. The ultimate goal was to progress his scaption and flexion to three sets of 20 repetitions with five-pound dumbbells. The use of five pound weights with three sets of 20 repetitions in the shoulder has been used in

Figure 4. Triceps extension.
4a. Initial and ending position. The patient stands with hands on handle bars, elbows in extension, shoulders neutral.
4b. Movement. The patient slowly allows the bar to be raised to 90 degrees of elbow flexion.

Supine AAROM and AROM exercises were added in multiple planes with a wand daily and were included in a home exercise routine. A rotator cuff strengthening program was conducted at home three days per week on non-consecutive days. Isometric exercise was issued for glenohumeral flexion, abduction, internal rotation (IR), external rotation (ER), and extension at varying angles within the patients available ROM. Each was conducted with 2 sets of 10 repetitions with 5-second holds and 5s rest breaks at maximal levels with 30 second rest breaks between sets. This was issued to prepare for a more complex exercise regime to come in later weeks.
the physical training of baseball positional players and pitchers. IR and ER at neutral abduction with 3 foot-long theraband was given. He was instructed to stand consistently 3 feet away from the door and place a towel roll between his humerus and body wall to avoid faulty compensations and optimize position of the rotator cuff.

During week 12, stretching with the hand behind head and back with a towel and pectoral stretches at 90 abduction and full available external rotation were added to address functional ROM. Grade III-IV postero-anterior joint mobilizations were performed later during rehabilitation as needed to the thoracic spine in accordance with Maitland’s recommendations. Strength was progressed accordingly for all previously described exercises through week 14 with detail given in Appendix 1.

Phase III- Return to Sport Phase- Weeks 15-17
Post-operatively
At this point, the patient demonstrated a 4/5 on MMT into glenohumeral scaption, flexion, abduction, IR and ER (in neutral abduction), compared to the non-involved side. It was decided to use a 4/5 on MMT to all above stated shoulder actions, along with a six-week strengthening protocol, as markers to progress to this phase. 4/5 on MMT was chosen by the authors because it was deemed necessary to have at least moderate amounts of force generating capacity to maintain joint congruity at submaximal levels with higher level activity. Further, we elected to use six weeks, as this was thought to allow enough time to achieve hypertrophic strength gains and allowed for appropriate cartilage healing in the inherently unstable GH joint. During the return to sport phase, the main focus was to develop advanced strengthening, control, and introduce resistance to actions of the squat, deadlift, and bench press while continuing to maintain and improve available ROM through passive and active ROM and joint mobility as previously described. It was also critical that this patient be educated on proper weight lifting modifications. During week 15, isotonic exercise at or above 90 degrees of shoulder elevation such as ER at 90 degrees of glenohumeral abduction (scarecrows) were added to enhance rotator cuff strength and stability in an upper extremity position similar to squats (Figure 6). To address dynamic stability and improve joint position sense, Body Blade™ exercise drills were utilized in the clinic, with the patient standing and moving through multiple planes of ROM. This was continued until discharge. Pushups on the wall using various stable and unstable surfaces were incorporated to strengthen the rotator cuff and scapular stabilizers in a closed kinetic chain manner.

At week 16, resistance was added to both the squat and deadlift. For the deadlift, the patient was instructed to concentrate on maximally contracting the lower extremities while using an underhand grip for the right hand during the deadlift (Figure 7) to...
avoid placing maximal stretch on the biceps muscle and tendon. Vertical pushups against the wall were progressed to an unstable surface for the upper extremities. The bench press was reintroduced at week 17. For the bench press, the patient was instructed to start with a ten-pound dumbbell in his involved arm with a spotter. He was allowed to progress by no more then five pounds per week. He also was educated to initiate barbell bench press when he was able to lift 50% of what he was lifting previously with dumbbells, in accordance with his goals. This was discussed to avoid compensating with his non-involved arm. Further, it was recommended to avoid excessive abduction and to maintain hand width no greater then 1.5x the biacromial width to avoid excessive strain on the rotator cuff. The patient was instructed to conduct lateral pull downs with his hands and elbows placed in front of his head. This avoids excessive shearing stress on the biceps long head tendon when the glenohumeral joint is at end-range external rotation at 90 degrees of abduction and also allows performance of the maneuver with the humerus in the scapular plane.
OUTCOME
The patient was seen 24 times over a nine-week period. He was discharged from physical therapy services at week 17 post-operatively. Both the patient and the primary author were in agreement that he reached his goals, other than his lifting targets, which could be safely progressed by him while applying the technique modifications to which he had been educated. His ROM had plateaued, but was comparable to the non-involved side (Refer back to Table 3). He was independent with his HEP progression, was able to work and perform his ADLs independently, and understood how his posture could relate to shoulder dysfunction. Finally, QuickDASH scores showed improvements beyond the standard error of measurement. The patient made large gains in the ADL section, improving from 81.8 at initial evaluation to 15.9 at discharge. The work-related module changed from 75 to 31.25. Sports module improved only from 100 to 75. This section of the QuickDASH was unlikely to change remarkably at this point in time seeing that he had just begun his return to power lifting maneuvers with external resistance including squats, deadlifts, and bench press, and that he did not want to return to lifting at 100% of his previous maximum lifts. However, it was expected that because foundational strength was developed and proper education in progression in HEP was provided to the patient, it was likely that his scores in all modules would continue to improve over the next 12-18 months.

At a two year follow-up, QuickDASH scores continued to show improvement, mostly in the sport module from 75 to 25, followed by work module (31.25 to 6.25) and ADLs (15.9 to 4.5), as seen in Table 4. The patient reported that he was bench pressing 150 pounds, squatting over 400 pounds, and deadlifting 365 pounds at four sets of 15 repetitions each as noted in Table 2. He felt that although he could lift more, he was unwilling to attempt to do so for fear of reinjuring his right shoulder, or any part of his body. Although he did complain of minimal intermittent right shoulder stiffness deep in his glenohumeral joint the patient was very satisfied with overall results.

DISCUSSION
Chondral defects occur in response to macrotrauma or microtrauma inflicted upon articular cartilage and rarely heal on their own. While joint replacement has been the treatment of choice for articular cartilage deficits in the glenohumeral joint, it often leaves the patient unable to return to desired levels of function. In the case of athletes, return to recreational sports is difficult to accomplish after total joint arthroplasty of the glenohumeral joint. Articular cartilage techniques such as the microfracture procedure, which stimulates subchondral bone and may provide the potential for articular cartilage healing, offer the athlete a chance to return to sport at the recreational level and beyond.

While post-operative rehabilitation following microfracture for the hip, tibiofemoral and patellofemoral, and talocrural joints have been defined, details regarding rehabilitation of the glenohumeral joint after microfracture procedures are lacking in the literature. The purpose of this case report was to describe the post-operative rehabilitation for a former power lifter who underwent an arthroscopic shoulder surgery for microfracture procedures of the glenohumeral joint, debridement of a type I SLAP lesion, and a subacromial decompression.

With regards to microfracture procedures performed in the tibiofemoral joint, patients older then 40 and 45 and those with lesion size greater then 2 cm² have demonstrated poorer outcomes compared to those who are younger and have smaller lesions. Despite being older then 45 and having a lesion size greater then 2 cm², this patient returned to recreational lifting, showed improvement on QuickDASH scores, and was satisfied with results at two-year follow up. Reinold et al reports a slower progression in patients with greater lesion sizes following microfracture procedure. It is possible that a rehabilitation program that advances slowly is more appropriate for those older then 40 years of age and/or with larger lesion sizes, and relate to why a successful outcome was achieved with this patient. Further, an accelerated progression was unnecessary as this patient was not interested in returning to a competitive sport that had a timeframe associated with return.

This patient was referred to physical therapy after eight weeks of CPM and self-induced PROM following arthroscopic microfracture procedures along with subacromial decompression and debridement of type I SLAP lesion. Placing initial AROM restrictions
may have aided in avoiding movements that place the developing cartilage at risk. Frisbie et al. states that hyaline-like cartilage was not found until eight weeks in the equine model. However, avoiding motion activates resorption of chondral surfaces and can likely weaken supporting joint musculature while causing joint restrictions and pain. The authors of this case report chose to err on the conservative side in order to ensure that abnormal forces were not placed across healing articular cartilage tissue. Future research should focus on whether early AROM places inappropriate torque or shear forces across the glenohumeral joint after chondral repair.

Some authors advocate for early post-operative weightbearing following microfracture procedure at the hip and tibiofemoral/patellofemoral joints. While it may be advantageous for early joint loading to occur in the more stable hip and knee joints, compressive and shear forces placed on the less stable glenohumeral joint during UE CKC exercises may predispose it to injury. The authors chose to hold off on weight-bearing (CKC) activities in this patient until adequate strength (4/5 on MMT) was found on physical examination. It should be noted that the baseline strength in a power lifter is unlikely to be similar to the average person. A 4/5 on MMT, as used in this case report as a measure for progression to a more difficult regime, may not be applicable in other populations. In future research it may be interesting to study the effects of earlier compressive loading in the glenohumeral joint following cartilage repair procedures. As cartilage is designed to protect against compressive forces, loading mesenchymal cells into compression in the early stages may assist in differentiation into chondrocytes.

This power lifter, despite being trained in proper lifting modifications after injury, was not being seen by the physical therapist while he independently progressed his bench, squat, and deadlift. Once a baseline strength and stability was developed for the shoulder, and the patient was educated in proper technique with lifting maneuvers, it seemed feasible to allow for early discharge. Familiarity with lifting routine prior to injury allowed the patient to progress independently and appropriately. In this patient, the primary author felt it unlikely that this lifter would resume training too rapidly because the patient stated he was not interested in returning. However, early discharge may not necessarily be an optimal strategy for more competitive athletes who may rush or resume training too quickly or intensely.

**CONCLUSION**

In conclusion, this patient who underwent an arthroscopic glenohumeral microfracture procedures, subacromial decompression, and debridement of type I SLAP lesion effectively returned to a recreational weight lifting. He returned to this level of participation with the guidelines outlined in the protocol described in this case report. The protocol utilized with this patient and the outcomes achieved can not be generalized to other patients who undergo microfracture procedures about the glenohumeral joint and should only be used as a guideline. Controlled research using a larger sample size would help to determine if a protocol such as the one used in this case report would be successful with a larger group of athletes. Thus, additional research should focus on developing optimal post-operative rehabilitation for a quick and safe return to activities of daily living and sport after microfracture of chondral surfaces in the glenohumeral joint. Research should examine whether the microfracture technique for the glenohumeral joint is a viable surgical option for patients with articular cartilage injuries that wish to return to sport. Finally, studies that describe patient categorization, classification, and clinical prediction rules identifying those who would benefit from microfracture procedure in the glenohumeral joint would also be beneficial.

**REFERENCES**


25. TBD. TBD. TBD. TBD. TBD.


Appendix 1. Post-operative rehabilitation following arthroscopic microfracture procedure with concomitant debridement of SLAP type I lesion and subacromial decompression.

I. Phase 1: protective PROM phase (day 1 post-arthroscopy-week 8)
Goals:
A. Protect surgical site from undue stress
B. Nourish articular cartilage to mold into appropriate tissue
C. Prevent negative effects of immobilization
D. Decrease pain and inflammation

<table>
<thead>
<tr>
<th>Weeks 1-6</th>
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<tbody>
<tr>
<td>1.</td>
<td>CPM at 90 degrees scaption, 90 degrees ER, 6H daily</td>
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<tr>
<td>2.</td>
<td>Cryotherapy as needed</td>
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<tr>
<th>Week 7-8</th>
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<tbody>
<tr>
<td>1.</td>
<td>Self-PROM into flexion/scaption</td>
</tr>
<tr>
<td>2.</td>
<td>Cryotherapy as needed</td>
</tr>
</tbody>
</table>

II. Phase 2: AROM and strengthening phase (Week 9-14)
Goals:
A. Restore full ROM
B. Preserve integrity of tissue
C. Restore muscular strength and endurance

<table>
<thead>
<tr>
<th>Week 9</th>
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<tbody>
<tr>
<td>1.</td>
<td>Education regarding posture, cryotherapy</td>
</tr>
<tr>
<td>2.</td>
<td>PROM into glenohumeral flexion, scaption, extension, and external rotation (ER)/internal rotation (IR) in scapular plane</td>
</tr>
<tr>
<td>3.</td>
<td>Glenohumeral joint mobilizations, grade I-II for pain</td>
</tr>
<tr>
<td>4.</td>
<td>AAROM/AROM supine into glenohumeral flexion, scaption, ER/IR in scapular plane and neutral abduction</td>
</tr>
<tr>
<td>5.</td>
<td>Home exercise program (HEP)</td>
</tr>
<tr>
<td></td>
<td>a. Wand exercises in scaption, flexion, ER/IR in neutral abduction, 10x10s holds, 5x/day</td>
</tr>
<tr>
<td></td>
<td>b. Squats, deadlifts with no external resistance</td>
</tr>
<tr>
<td></td>
<td>c. Isometrics in glenohumeral flexion, abduction, ER/IR in neutral abduction, 2x10 reps, 5s holds, 1x/day, 5x/week</td>
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<tr>
<td></td>
<td>d. Forearm, wrist, hand-gripping exercises</td>
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<td></td>
<td>e. Serratus anterior punches supine, 2x10-20 repetitions without external resistance, conducted 1x/day, 5x/week</td>
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<td></td>
<td>f. Tricep extensions/unilateral bicep curls standing, 2x20 repetitions, 5 pounds, 3x/week on non-consecutive days</td>
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<thead>
<tr>
<th>Week 10</th>
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<tbody>
<tr>
<td>1.</td>
<td>Progress PROM adding abduction</td>
</tr>
<tr>
<td>2.</td>
<td>Joint mobilizations</td>
</tr>
<tr>
<td></td>
<td>a. Sternoclavicular joint, into both superior and inferior direction, grade III-IV</td>
</tr>
<tr>
<td></td>
<td>b. Scapulothoracic joint, into upward rotation, grade III-IV</td>
</tr>
<tr>
<td></td>
<td>c. Glenohumeral joint, into posterior and inferior direction, grade II-III</td>
</tr>
<tr>
<td>3.</td>
<td>AAROM and AROM- glenohumeral flexion and scaption standing</td>
</tr>
</tbody>
</table>
### Appendix 1. Post-operative rehabilitation following arthroscopic microfracture procedure with concomitant debridement of SLAP type I lesion and subacromial decompression. *Continued.*

4. **HEP**
   a. Wand exercises continued from week 9
   b. Squats, deadlifts with no external resistance continued from week 9
   c. Glenohumeral isometrics continued from week 9
   d. Forearm, wrist, hand-gripping exercises continued from week 9
   e. Increase serratus anterior punches to 1-2 pounds
   f. Increase bicep/tricep exercises to 10 pounds
   g. Standing rows with theraband, 2x20 repetitions, 3x/week on non-consecutive days

#### Week 11
1. Progress PROM adding ER/IR stretching at 90 degrees abduction
2. Joint mobilizations- add grade III-IV to glenohumeral joint, same direction as week 10
3. AROM glenohumeral scaption and flexion continued from week 10
4. **HEP**
   a. Wand exercises continued from week 9
   b. Squats, deadlifts with no external resistance continued from week 9
   c. Forearm, wrist, hand-gripping exercises continued from week 9
   d. Isotonic strengthening for glenohumeral joint, 2x20 repetitions, 3x/week, on non-consecutive days
      i. Flexion and scaption standing with 1 pound
      ii. Deltoid wings with 1-2 pounds
      iii. IR/ER with theraband at neutral abduction
   e. Increase serratus anterior punches to 3 pounds
   f. Increase bicep/tricep exercises to 12 pounds
   g. Standing rows with theraband continued from week 10

#### Week 12
1. Progress PROM- add towel stretching behind head and back, wall pectoral stretch at 90 degrees abduction, 10x10 seconds 2-3x/day each, 5x/week
2. Joint mobilizations- add thoracic spine mobilizations, into anterior direction, and continue with GH joint mobilizations from week 11
3. AROM glenohumeral scaption and flexion continued from week 10
4. **HEP**
   a. Wand exercises continued from week 9
   b. Squats, deadlifts with no external resistance continued from week 9
   c. Forearm, wrist, hand-gripping exercises continued from week 9
   d. Isotonic strengthening- glenohumeral joint
      i. Increase flexion and scaption to 2 pounds
      ii. Increase deltoid wings to 3 pounds
      iii. Increase IR/ER with theraband
   e. Increase serratus anterior punches to 4 pounds
   f. Increase biceps/triceps exercises to 15 pounds
   g. Increase standing rows resistance with theraband

#### Week 13
1. Progress PROM
2. Joint mobilizations- continue from week 12
3. AROM glenohumeral scaption and flexion continued from week 9
Appendix 1. Post-operative rehabilitation following arthroscopic microfracture procedure with concomitant debridement of SLAP type 1 lesion and subacromial decompression. *Continued.*

<table>
<thead>
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<th>Week 14</th>
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<tbody>
<tr>
<td>1. Progress PROM</td>
</tr>
<tr>
<td>2. Joint mobilizations continued from week 12</td>
</tr>
<tr>
<td>3. AROM glenohumeral scaption and flexion continued from week 10</td>
</tr>
<tr>
<td>4. HEP</td>
</tr>
<tr>
<td>a. Wand exercises continued from week 9</td>
</tr>
<tr>
<td>b. Squats, deadlifts with no external resistance continued from week 9</td>
</tr>
<tr>
<td>c. Forearm, wrist, hand-gripping exercises continued from week 9</td>
</tr>
<tr>
<td>d. Isotonic strengthening- glenohumeral joint</td>
</tr>
<tr>
<td>i. Increase flexion and scaption to 5 pounds</td>
</tr>
<tr>
<td>ii. Increase deltoid wings to 5 pounds</td>
</tr>
<tr>
<td>iii. Increase IR/ER with theraband</td>
</tr>
<tr>
<td>e. Increase serratus anterior punches to 5 pounds</td>
</tr>
<tr>
<td>f. Biceps/triceps exercises continued from week 13</td>
</tr>
<tr>
<td>g. Standing rows continued from week 13</td>
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**III. Phase 3: Return to recreational lifting/sport phase (Week 15-)**

**Goals:**
A. Maintain full ROM  
B. Improve muscular strength, endurance, and stability  
C. Gradually return to power lifting tasks

<table>
<thead>
<tr>
<th>Week 15</th>
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<tbody>
<tr>
<td>1. PROM</td>
</tr>
<tr>
<td>2. Joint mobilizations as needed, continued from week 12</td>
</tr>
<tr>
<td>3. AROM glenohumeral scaption and flexion continued from week 10</td>
</tr>
<tr>
<td>4. HEP</td>
</tr>
<tr>
<td>a. Wand exercises continued from week 9</td>
</tr>
<tr>
<td>b. Squats, deadlifts with no external resistance continued from week 9</td>
</tr>
<tr>
<td>c. Forearm, wrist, hand-gripping exercises continued from week 9</td>
</tr>
<tr>
<td>d. Wall pushups, 2x20, on stable surface, 3x/week, on non-consecutive days</td>
</tr>
<tr>
<td>e. Body Blade exercise through full scaption ROM, 3x/week, on non-consecutive days 20x</td>
</tr>
<tr>
<td>f. Isotonic strengthening- glenohumeral joint</td>
</tr>
<tr>
<td>i. Flexion/scaption continued from week 14</td>
</tr>
<tr>
<td>ii. Deltoid wings continued from week 14</td>
</tr>
<tr>
<td>iii. IR/ER with theraband continued from week 14</td>
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Appendix 1. Post-operative rehabilitation following arthroscopic microfracture procedure with concomitant debridement of SLAP type I lesion and subacromial decompression. Continued.

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<tr>
<td>iv.</td>
<td>Scarecrows, 1-2 pounds, 2x20</td>
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<tr>
<td>g.</td>
<td>Serratus anterior punches continued from week 14</td>
</tr>
<tr>
<td>h.</td>
<td>Increase biceps/triceps exercises to 25 pounds</td>
</tr>
<tr>
<td>i.</td>
<td>Add unilateral bent over rows, 20 pounds, 2x20 repetitions, 3x/week, on non-consecutive days</td>
</tr>
</tbody>
</table>

**Week 16**
1. PROM
2. Joint mobilizations as needed, continued from week 12
3. AROM glenohumeral scaption and flexion continued from week 10
4. HEP
   a. Wand exercises continued from week 9
   b. Forearm, wrist, hand-gripping exercises continued from week 9
   c. Wall pushups, 2x20, on unstable surface, 3x/week, on non-consecutive days
   d. Body Blade exercises continued from week 15
   e. Dead lifts, 60 pounds, 2x20, 3x/week, on non-consecutive days
   f. Squats, 95 pounds, 2x20, 3x/week, on non-consecutive days
   g. Isotonic strengthening- glenohumeral joint
      i. Flexion/scaption continued from week 14
      ii. Deltoid wings continued from week 14
      iii. IR/ER with theraband continued from week 14
      iv. Increase scarecrows to 3-4 pounds
   h. Serratus anterior punches continued from week 14
   i. Increase biceps/triceps exercises to 30 pounds
   j. Increase bent over rows to 25 pounds

**Week 17**
1. PROM
2. Joint mobilizations as needed, continued from week 12
3. AROM glenohumeral scaption/flexion continued from week 10
4. HEP
   a. Wand exercises continued from week 9
   b. Forearm, wrist, hand-gripping exercises continued from week 9
   c. Add dumbbell bench press, starting with 10 pounds unilaterally
   d. Body Blade exercises continued from week 15
   e. Increase deadlifts to 70 pounds
   f. Increase squats to 135 pounds
   g. Isotonic strengthening- glenohumeral joint
      i. Flexion/scaption continued from week 14
      ii. Deltoid wings continued from week 14
      iii. IR/ER with theraband continued from week 14
      iv. Increase scarecrows to 5 pounds
   h. Serratus anterior punches continued from week 14
   i. Biceps/triceps exercises continued from week 16
   j. Increase bent over rows to 30 pounds
ABSTRACT

The benefits and proposed physiological mechanisms of eccentric exercise have previously been elucidated and eccentric exercise has been used for well over seventy years. Traditionally, eccentric exercise has been used as a regular component of strength training. However, in recent years, eccentric exercise has been used in rehabilitation to manage a host of conditions. Of note, there is evidence in the literature supporting eccentric exercise for the rehabilitation of tendinopathies, muscle strains, and in anterior cruciate ligament (ACL) rehabilitation. The purpose of this Clinical Commentary is to discuss the physiologic mechanism of eccentric exercise as well as to review the literature regarding the utilization of eccentric training during rehabilitation. A secondary purpose of this commentary is to provide the reader with a framework for the implementation of eccentric training during rehabilitation of tendinopathies, muscle strains, and after ACL reconstruction.

Key Words: eccentric exercise, rehabilitation, tendinopathy, muscle strain, negative work, anterior cruciate ligament

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INTRODUCTION
Over approximately the last fifteen years, use of eccentric exercise in rehabilitation has increasingly gained attention in the literature as a specific training modality. That being said, the concept of eccentric exercise is not new. To the authors’ knowledge, the earliest investigation of eccentric versus concentric exercise was published in 1938. Eccentric exercise has been primarily described in the rehabilitation literature describing the management of tendinopathies. However, evidence is mounting to support its use in the treatment of muscle strains, with most of the rehabilitation literature relating to the use of eccentric training in rehabilitation after hamstring injuries. Finally, eccentric training has been used in recent years as a part of rehabilitation following ACL reconstruction. The purpose of this clinical commentary is to present the physiologic basis for eccentric exercise and to discuss the evidence in support of eccentric exercise in the management of patients recovering from tendinopathies, muscle strains, and ACL reconstructions. Additionally, suggested implementation of eccentric exercise in the management of these conditions will be highlighted. Although important to the clinician, the causes of these injuries as well as the mechanisms and origins of pain associated with these injuries are beyond the scope of this commentary. Further, other interventions used typically with these conditions such as stretching and modalities will not be discussed. It is important to note that although the focus of this commentary details the benefits of eccentric training, it is the authors’ suggestion that a comprehensive rehabilitation approach include both concentric and eccentric training. It is not the authors’ intent to advocate exclusive use of eccentric training, but rather to point out the investigated benefits of and utilization of eccentric exercise as a part of a comprehensive rehabilitation program.

PHYSIOLOGY OF ECCENTRIC EXERCISE
During voluntary contraction of a muscle, speed of contraction and ability to exert tension are inversely related. The faster a muscle contracts concentrically, the lower the tension it is able to generate. Tension in muscle fibers when lengthening is considerably greater than when muscle fibers are shortening. During negative work (eccentric exercise), the oxygen consumption rarely rises to more than twice the resting value. Previous studies have shown that when a muscle is eccentrically lengthened, the energy requirement falls substantially in comparison to concentric contractions because ATP breakdown and heat production are both slowed. Bigland-Ritchie et al found: 1) less muscle activity was required to maintain the same force during negative work, 2) fewer muscle fibers were required to exert a given force, and 3) there was a substantial reduction in oxygen uptake when fibers were eccentrically lengthened. Furthermore, with increased heat generation during concentric/positive work, there is a concurrent increase in cellular metabolism. Thus, more waste products will be generated with concentric work, potentially leading to chemical irritation of nerves and eventually pain. Abbott et al measured oxygen uptake in subjects during bicycle ergometry. Positive work (concentric exercise) resulted in more oxygen consumption than negative work. Abbott and others then performed a follow up study examining the relationship between oxygen consumption and work. Oxygen consumption was nearly three times larger at great force and low speed than at small force and high speed. The above studies show that eccentric exercise results in less oxygen consumption, greater force production, and less energy expenditure than concentric exercise.

TENDINOPATHY
Tendon injuries account for 30-50% of injuries in sports. Specifically, chronic problems caused by overuse of tendons result in 30% of all running-related injuries, and elbow tendon injuries can be as high as 40% in tennis players. Incidence of patellar tendinopathy is reported to be as high as 32% and 45% in basketball and volleyball players, respectively. Tendon pathologies not only lead to lost time and performance declines in sports, but also can result in long term damage to tendons that can affect daily function.

REVIEW OF LITERATURE: ECCENTRIC TRAINING IN TENDINOPATHY
Many studies recently have substantiated eccentric exercise as an effective treatment for tendinopathies. Eccentric training may be effective for tendinopathies based on work by Williams who found that
In most patients, both of which correlated with less pain, in a group of subjects with chronic Achilles tendinosis who were trained using the Alfredson et al\textsuperscript{16} eccentric calf protocol. Mahieu et al\textsuperscript{20} found that eccentric training of the plantar flexors resulted in positive changes to the mechanical properties of the plantar flexor muscle-tendon tissue including passive resistive torque, dorsiflexion range of motion, and stiffness.

Several authors have conducted studies that support the use of eccentric exercise in the treatment of a variety of tendinopathies. Jonsson and Alfredson\textsuperscript{21} studied athletes with jumpers knee (patellar tendinopathy) who were randomized into either an eccentric or concentric exercise group and treated for 12 weeks. At mean follow-up of 32 months, the eccentric exercise group was still satisfied subjectively and “sports active”, although it was not specifically stated whether they returned to sport or not. Subjects in the concentric exercise group had undergone surgery or sclerosing injections. In another study of elite volleyball players with patellar tendinopathy, Young et al\textsuperscript{22} found that subjects improved from baseline at 12 weeks and 12 months. In contrast, Visnes et al\textsuperscript{23} found no effect of eccentric training on jumper's knee in volleyball players during the competitive season. The lack of results from eccentric training in this study may be due to the fact that athletes continued to participate in volleyball during the competitive season. Because rest is often advocated as a component of rehabilitation, failing to cease the aggravating activity may have perpetuated their injury and contributed to the lack of results.

Systematic reviews of literature by Wasielewski \& Kotsko\textsuperscript{24}, as well as Kingma et al\textsuperscript{25} examined the effects of eccentrics in reducing pain and improving strength in subjects with lower extremity tendinosis and chronic achilles tendinopathy, respectively. These reviews revealed that eccentric exercise may reduce pain and improve strength in patients with lower extremity tendinopathies, but whether it is better than other forms of rehabilitation has yet to be determined. Therefore, no definitive conclusions can be made regarding whether or not the performance of eccentric exercise alone is superior to concentric-eccentric training or concentric-minimized training.
IMPLEMENTATION OF ECCENTRICS IN REHABILITATION OF TENDINOPATHIES

Regardless of the involved tendon, load and volume of exercise should be progressed gradually and should be dictated by the amount of pain experienced by the athlete. Because the athlete is recovering from injury, the authors of this commentary advise that training load not be determined by a one repetition maximum (1 RM). Further, some of the exercises are for targeted muscle groups (elbow extensors for elbow injury) and determining a 1 RM is not practical or advised. The Alfredson et al16 protocol has been used in previous studies and appears to be a safe, effective method of implementing the eccentric training program for tendinopathies. Unfortunately, the Alfredson protocol was described for and used in the treatment of achilles tendinopathies and their exact recommendations may not be appropriate for all tendons or regions. The clinician may use the protocol for an example of volume and frequency of training, but in lieu of added weights to a backpack, adding weights to a leg press or using various resistances of ankle weights and dumbbells would seem appropriate. For tendinopathies in the shoulder, elbow, or hand, increases by five-kilogram increments is likely inappropriate and resistances should be adjusted accordingly.

Curwin27 has previously proposed a method to determine training load in eccentric training for tendon injuries that is based on number of repetitions completed and the amount of pain experienced. One significant difference between Curwin’s and Alfredson’s programs is that the athlete performs both the concentric and eccentric portion of the exercise in Curwin’s program, with the eccentric portion being performed faster. Alfredson encouraged a slow, 3-4 second eccentric contraction. In Curwin’s protocol, they suggest that the athlete should experience pain and fatigue between 20 and 30 repetitions at a given load, when performing three sets of 10 repetitions. Their rationale for experiencing pain is based on the premise that exercise load should be determined by the tendon tolerance, which is indicated by pain experienced during the exercise. Curwin and Stanish determined empirically that pain felt before 20-30 repetitions would likely be accompanied by worsening of symptoms. Pain felt before that range is generally accompanied by worsening of symptoms and either load or speed is of contraction should be decreased. If there is no pain after 30 repetitions, the stimulus is inadequate. Either load or the speed of exercise performance should be increased, but not both simultaneously. Pain experienced during the exercise protocol should be similar to the pain experienced during the athlete’s functional activity with an acceptable, moderate increase from that point on in the program. During the first session, load is increased until symptoms appear. After a general warm-up (bike, upper body ergometer), athletes perform two 30 second stretches of the involved muscle group.

Based on the clinical experience of the authors and Ratamess and others,20 it is recommended that 6-12 repetitions over four sets be completed to emphasize strength in the muscle-tendon complex. The athletes use the load from the six repetition resistance and build up to twelve repetitions prior to increasing load again. Anecdotally, the authors have found this method to be progressive, yet safe, with less overall volume to help enhance recovery. Additionally, the authors advocate three to four sessions per week instead of every day. The authors propose that “heavy load” is a misnomer in the Alfredson et al16 study because the volume of exercise is rather high and the load is low given the amount of exercise that is tolerated by the athletes. Ultimately however, dosing must be based on tendon reactivity and patient response.

The authors suggest having the clinician or athlete perform the concentric portion of the exercise passively or with the assistance of the uninvolved limb during closed chain exercises, followed by having the athlete perform the eccentric portion of the exercise independently. Based on clinical experience, the authors propose that the concentric portion of the exercise can be attempted without assistance once non-sport activities, like walking and stair climbing, are pain free. As with eccentric exercise, progression of the concentric portion of exercise should involve a gradual increase. Once the concentric portion of exercise is pain free, the authors suggest that athletes can begin jogging or more sport specific activities. A progression from individual drills to team activities is a disciplined way to reintroduce an athlete to their chosen sport. If they have
pain, they should return to the previous regimen until they are pain free. A cool down activity (i.e. recumbent bike) followed by stretching of involved muscles should follow the program. Although Thacker and others\textsuperscript{29} have found that there is insufficient evidence to support pre- or post-exercise stretching, lack of musculotendinous flexibility is a common finding in chronic tendinopathies\textsuperscript{27} and should be a part of the program if identified. Ice to the affected area is advised to limit post-exercise pain and potential inflammation. Athletes should be warned that eccentric exercise may make them sore initially, and that this is to be expected. Although the above recommendations are anecdotal in nature and reflect clinical experience, the authors of this review have had success with the combined stretching and icing approach.

**HAMSTRING STRAIN**

Most of the literature on muscle strains revolves around injuries to the hamstring muscle group, therefore, they will be the focus of this section. The reader is directed to the review by Hibbert et al\textsuperscript{30} on the effectiveness of eccentric strength training for the prevention of muscle strains.

Hamstring strains are among the most common injuries sustained by athletes.\textsuperscript{31-34} Hamstring muscle strains are currently the most common injury in professional soccer\textsuperscript{35} and they account for 29% of injuries in track and field sprinters.\textsuperscript{36} They are common in sports that require maximum sprinting, kicking, acceleration, and change of direction.\textsuperscript{36} The average amount of time lost from competition and training is 18 days,\textsuperscript{37} but has also been reported to vary between 8 and 25 days.\textsuperscript{38} Furthermore, athletes must deal with persistent symptoms and a likelihood of re-injury, found to be present in anywhere from 12-31% of those who sustain a hamstring strain.\textsuperscript{39,40} Highest risk of recurrence is within the first two weeks of returning to sport.\textsuperscript{41} Greig and Siegler\textsuperscript{42} performed an intermittent treadmill protocol to replicate soccer-specific fatigue. Peak isokinetic eccentric knee flexor strength was measured at three speeds at the end of a simulated (passive) halftime and at the end of the treadmill protocol. Eccentric hamstring strength decreased with increased work time and after the halftime interval. Athletes may therefore be at risk of injury with increased time in competition and shortly after halftime.

Muscle strain injuries are thought to occur when muscles are actively lengthened to greater than resting lengths.\textsuperscript{36} The combination of rapid eccentric contraction with active muscle contraction elsewhere in the musculotendinous unit can produce mechanical strain leading to muscle injury.\textsuperscript{43} In ball sports, hamstring injury tends to occur when turning sharply or cutting, whereas in sprinting the injury occurs while running at full speed without a change of direction.\textsuperscript{32,44,45} Because of the biarticular nature of the hamstrings, they can be vulnerable to injury during running, cutting, and sprinting; all of which involve a combination of hip flexion and knee extension, which maximally lengthens the hamstring group. Hamstrings have to contract rapidly to generate a large amount of power.\textsuperscript{44} Several authors have suggested that most hamstring injuries occur during the late swing and early contact phases of running.\textsuperscript{44-46}

Because the biceps femoris has greater lengthening and electrical activity during the late swing phase of running,\textsuperscript{46} it may be more susceptible to injury than the medial hamstrings. Kouloris and Connell\textsuperscript{47} found that biceps femoris strains accounted for 80% of the 170 hamstring injuries that occurred in athletes. Small et al\textsuperscript{48} found that reductions in eccentric strength occur during later stages of simulated soccer match play. Consequentially, greater muscle strength imbalance between eccentric hamstring and concentric quadriceps strength has also been observed in later stages of match play or with fatigue.\textsuperscript{49-50}

Sugiura et al\textsuperscript{44} performed a prospective study of elite sprinters to determine a relationship between strength and hamstring injury within 12 months of testing. This was the first study to examine the concentric and eccentric isokinetic strength of the hip extensors, quadriceps, and hamstrings that reflects their actions in late swing or early contact. Testing was performed on 30 male elite sprinters. Injuries occurred in six subjects. Eccentric weakness of the hamstrings at 60° per second was found to be a common factor among those who sustained injuries. Side to side comparison revealed that the injury always occurred on the weaker side. Similar findings were elucidated by Orchard et al\textsuperscript{43} who found that hamstring muscle injury was associated with low
hamstring-to-quadriceps ratio at 60° per second on the injured side and a low side-to-side peak torque at 60° per second in a group of Australian football players. Therefore, it may be advantageous to include eccentric training as part of either a training regimen or rehabilitation protocol to minimize asymmetries or to help maximize strength gains.

**REVIEW OF LITERATURE: ECCENTRIC TRAINING IN PREVENTION OF HAMSTRING STRAINS**

Small et al. investigated the effect of eccentric hamstring strengthening during soccer training. The objective was to evaluate if there was a difference in eccentric strength with fatigability and to see if eccentric training would attenuate the effects of fatigue. Sixteen semiprofessional soccer players completed a 90-minute simulated soccer game. At half time and at the conclusion of the game, the athletes performed isokinetic testing at 120° per second for the quadriceps and hamstrings. Two groups of subjects performed the “Nordic hamstring” eccentric exercise (Figure 1a, 1b) either during the cool-down or the warm-up period twice weekly during the 8-week intervention program. The group that performed the exercise in the cool down period showed significant increases in eccentric hamstring peak torque and the functional eccentric hamstring to concentric quadriceps ratio post-intervention compared to the warm-up group. Based on the results of this study, eccentric strength training conducted post-training significantly reduced the effects of fatigue. Therefore, performing eccentric training with fatigue may have a time-dependent beneficial effect.

Askling and others examined the relationship between eccentric training and subsequent injury in elite male soccer players. Thirty players were divided among two groups, one of which performed eccentric training in addition to the typical soccer team training 1-2x/week for 10 weeks, while the control group performed only the team training. Isokinetic hamstring strength and maximal running speed were measured in both groups before and after the training period. Injuries were monitored over 10 months. The eccentric training group had significantly fewer hamstring injuries (3/15) compared to the control group (10/15). In addition, the training group showed statistically significant improvements in strength and speed.

Arnason et al. compared “eccentric hamstring low- ers” (Nordic hamstring exercise) to contract-relax hamstring stretching with incidence and severity of hamstring strains in professional soccer players. Par-
Participants performed one of three interventions: warm up stretching performed independently with contract-relax stretching, partner-assisted contract-relax hamstring flexibility exercises, and eccentric hamstring exercises. The overall incidence of hamstring strains was 65% lower in the eccentric group. While incidence of hamstring injury was lower in the eccentric training group, injury severity and re-injury rates were not statistically significantly different.

Gabbe et al performed a randomized controlled trial that examined the relationship between eccentric strengthening and prevention of hamstring strains in 220 male football players in the Victorian Amateur Football Association. One group performed the “hamstring lowers” as previously described and the other performed stretching and range of motion exercises. Unfortunately, compliance was an issue in this study, but among players who completed at least two sessions, the incidence of hamstring strains in the eccentric group was 4% compared to 13% in the stretching and range of motion group. Brooks et al examined the effects of eccentric hamstring lowers and stretching on incidence and severity of hamstring strains in 546 professional rugby players. The intervention group was reported to display significantly lower incidence and severity of hamstring injury than the stretching group and the conventional stretching/strengthening group.

Holcomb et al investigated whether a hamstring-emphasized resistance training program would improve isokinetic hamstring:quadriceps ratios in a group of 12 female NCAA soccer players. Subjects were tested before and after completing a six week training program with two randomly chosen specific exercises from a group of six exercises targeting the hamstrings. Subjects performed both the concentric and eccentric phases of the exercises. The hamstrings:quadriceps ratio was measured at 60, 180, and 240° per second. Six weeks of strength training emphasizing the hamstrings significantly increased the eccentric hamstring:concentric quadriceps ratio from below 1.0 to over 1.0. Eccentric hamstring:concentric quadriceps ratio has been advocated to be at least 1.0.

While the above studies used eccentric training in healthy subjects or in the context of prevention of future injury, the data is nonetheless promising about the positive effects of eccentric training on strength, altering hamstring to quadriceps ratios, and preventing injury. Because of that, the clinician can surmise that the use of eccentric training as a part of the recovery after hamstring strains may lead to improved outcomes and decreased risk of future injury. It should be noted that the authors are not advocating the elimination of the concentric portion of an isotonic exercise, but rather increasing eccentric emphasis by assisting during concentric exercise or concentrically-minimized exercises.

IMPLEMENTATION OF ECCENTRICS TRAINING IN HAMSTRING STRAINS

Based on the literature presented on the varied outcomes related to eccentric training, it is evident that there may be promise in making eccentric training an integral part of the rehabilitation program after a hamstring strain. The authors of this commentary wish to focus on exercise interventions in lieu of isokinetic exercise interventions because access to isokinetic devices for a majority of clinicians is limited. The exercises subsequently discussed undeniably have a concentric component. As stated previously, the authors are not advocating elimination of the concentric portion of any exercise. It is generally accepted that it is virtually impossible and undesirable to eliminate the concentric portion entirely. However, the authors suggest that clinicians should have an increased awareness regarding how to design exercises to have a greater eccentric emphasis and should also consider how eccentric exercise should be a part of a systematic and progressive approach to training after injury to the hamstrings.

Comfort et al proposed a rehabilitation and conditioning continuum for hamstring rehabilitation. After the initial inflammatory phase resolves, initial goals are to restore range of motion and begin strengthening using hamstring-specific exercises that are primarily open kinetic chain and non-weight bearing. Once non-weight bearing exercises are tolerated, they suggest implementing low-velocity eccentric activities such as stiff leg dead lifts (Figure 2), eccentric hamstring lowers/Nordic hamstring exercise, and split squats (Figure 3a, 3b). The next phase involves higher velocity eccentric exercises that include plyometric and sport specific activities designed to increase hamstring torque and lower extremity power.
Examples include squat jumps, split jumps, bounding, and depth jumps. Finally, sport specific progressions should complete the program. Comfort et al suggest progressing from unidirectional linear movements to bidirectional and then multidirectional movements. Some of these exercises may include single leg bounding, backward skips, lateral hops, lateral bounding, and zigzag hops and bounding.

Brughelli and Cronin suggested a host of exercises in lieu of the “eccentric lowers/Nordic hamstring” exercise in the training of a non-injured athlete. They contend that while the “Nordic hamstring” may be a good exercise alternative, it is both bilateral and open chain. Because of this, one leg may be able to compensate for the involved limb. As stated previously, the hamstrings are a biarticular muscle and should be trained as such. Clark et al found that after four weeks of training with the Nordic hamstring exercise, vertical jump and peak torque of the hamstrings increased. Brughelli and Cronin propose that eccentric exercise interventions for reducing hamstring strains should include the following: high force, maximal muscle elongation, high velocity, multi-joint movements, closed-chain exercises, unilateral exercises, and easily implemented, cost-effective exercises.

Figure 2. Stiff leg deadlifts.

Figure 3a, b. Split squat and progression.
Isokinetic devices could be used for eccentric training, however are often cost-prohibitive, require proper patient training, and also require adequate space. Isokinetic exercise does not offer functional velocities for exercise training nor does it provide multi-joint, closed-chain options. In contrast, several exercises are advocated that require little equipment for effective implementation and fulfill the suggestions of Burghelli and Cronin. Some examples of these exercises include plyometric box jumps, eccentric backward steps (Figure 4), eccentric lunge drops (Figure 5a, 5b), eccentric forward pulls (Figure 6), single and double leg deadlifts, and in split stance deadlift ("good morning" exercise) with the load in front of the body, as opposed to a posterior load utilized during the traditional performance of this exercise (Figure 7a, 7b).

Figure 4. Eccentric backward steps. The subject resists the clinician’s attempt to push him/her backwards.

Figure 5a, b. Eccentric lunge drops. The subject begins in a split stance position and drops rapidly into a lunge position.

Figure 6. Eccentric forward pulls. The subject resists forward pull by the clinician.
Heiderscheit and others recently commented on hamstring injuries and provided a structural framework for rehabilitation. Once the initial inflammatory phase has resolved, low intensity, pain free exercises involving the entire lower extremity and trunk are implemented to minimize atrophy and develop neuromuscular control of the lower extremities and trunk. Phase two exercises involve progression of intensity and range of motion based on patient tolerance. In stage two, eccentric exercises are initiated. Exercises are submaximal at the mid-length of the muscle and also include trunk stabilization exercises and agility training in the frontal and transverse planes. Finally, stage three exercises involve sport-specific exercises that involve quick direction changes, functional movement patterns, and eccentric exercises progressing to include end-range movement.

The authors of this commentary agree with Heiderscheit et al that initial phases of rehabilitation should focus on controlling pain, edema, and inflammation as well as tolerance of pain-free concentric exercises prior to initiation of eccentrics. Intuitively, eccentric exercises should be initiated in low to middle ranges of motion in order to limit the risk of further injury.

Walking lunges, multi-directional step ups, split squats, stiff leg dead lifts, and “modified good mornings” should be implemented within pain free range of motion. Additionally, the authors of this commentary recommend doing the Nordic hamstring/eccentric lowers with elastic band assistance (Figure 8) in rehabilitation, and the previously described technique (Figure 1a, 1b) would be a progression. By using a heavy-resistance band, the recovering athlete has the elasticity of the band to assist in both the concentric and eccentric portions of the exercise. As the athlete tolerates this exercise and completes it throughout the full range of motion, the band can be eliminated.

The authors suggest agility ladder drills and shuffling can be used as either an “active recovery” or as an active warm-up. As the athlete continues to tolerate increased range of motion during exercises, load should be increased with a concomitant decrease in volume. For hamstring strengthening, the authors of this manuscript refer the reader to the American College of Sports Medicine’s Position Statement by Ratamess and colleagues for progression of resistance exercise. The authors propose increasing speed of performance to more closely replicate...
sport demands. Athletes can perform exercises in a given time frame (i.e. continuous for 35-45 seconds for a hockey player) or with modifications in work: rest ratios (i.e. football player performing multiple 7-second exercise bouts with 25-35 second rest) to more closely mimic the metabolic demands of their sport. Once multi-directional closed and open chain exercises are tolerated, the athlete’s program should be progressed to require the athlete to run up hill in order to improve stride length, and run downhill in order to improve stride frequency as well as to condition the athlete to tolerate frequent, rapid shifts between concentric and eccentric movements. Additionally, the authors propose performing eccentric hamstring exercises at the close of the training session when the athlete is fatigued. Previous researchers have found that strength production in the hamstrings declines with fatigue,42 therefore training when fatigued may provide protection against injury.

ANTERIOR CRUCIATE LIGAMENT (ACL) RECONSTRUCTION

Injury to the ACL is a common and significant knee injury, potentially resulting in limitations in range-of-motion, degenerative changes of the knee joint and muscular atrophy.62 Muscular atrophy greater than 20% and strength loss exceeding 30% have been demonstrated strength persisting for several years after surgery.63,64,88-77 Hamstring and gracilis muscle volume deficits of 10% and 30% were found post ACL reconstruction with autologous semitendinosus-gracilis graft.77,78 Amelioration of these deficits continues to be a clinical challenge requiring systematically progressed strengthening protocols that encompass all components of lower extremity function.

High intensity and accelerated intervention programs have long been suggested as optimal and reported as safe following ACL reconstruction.71,79-83 LaStayo et al84 suggested that eccentric training for the quadriceps was more effective in recovery of strength deficits post ACL reconstruction due to this type of training promoting greater changes in neural activation and muscle hypertrophy. Investigation of higher intensity rehabilitation training (producing increasingly greater strain on the ACL graft) versus a program producing minimal strain on the graft found no differences in knee laxity, activity level, function, and patient satisfaction up to 2 years postoperatively.85

Although it was concluded that these higher intensity programs were safe, Beynnon et al86 emphasized use of caution with increasing the frequency and magnitude of quadriceps activity due to concern of increasing anterior knee laxity. Additionally, it has been demonstrated that when applied gradually and progressively, an eccentric (or negative-work) exercise training for the quadriceps is safe for these patients and can be tolerated without damage.84,86-89 Eccentric knee extensor training was purported to be essential for restoration of the functional capacity of the ACL reconstructed knee due to findings of significantly larger concentric and eccentric peak torque deficiencies in the knee extensors as compared to the knee flexors.90

Mikkelsen et al91 compared a closed kinetic chain (CKC) training program versus training with CKC...
and open kinetic chain (OKC) exercise starting at 6 weeks post ACL reconstruction. Anterior knee laxity (KT-1000 arthrometer), isokinetic concentric and eccentric quadriceps and hamstring muscle torque (isokinetic dynamometry before and six months after surgery), and return to preinjury sports level (questionnaire at an average of 31 months post surgery) were measured in 44 patients with unilateral ACL reconstruction. No significant differences in anterior knee laxity were noted between the groups at six months post surgery. Those performing OKC in addition to CKC increased their quadriceps torque to a significantly greater degree than those performing only CKC exercises. No significant differences were noted between groups for hamstring muscle torque. The number of patients returning to preinjury sports level participation was greater in the OKC/CKC exercise group than the CKC exercise only

<table>
<thead>
<tr>
<th>Stage</th>
<th>Diagnosis</th>
<th>Macroscopic Pathology</th>
<th>Histologic Findings</th>
<th>Clinical Signs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Healthy</td>
<td>No inflammation</td>
<td>Organized collagen, absent blood cells</td>
<td>Firm tendon, not painful, absent swelling, normal temperature</td>
</tr>
<tr>
<td>I</td>
<td>Acute tendinitis</td>
<td>Symptomatic tendon degeneration, increased cellularity, vascular disruption, inflammation of paratenon</td>
<td>Degenerative changes w/ microtears, inflammatory cells in paratenon; focal collagen disorientation</td>
<td>Acute swelling, pain, local tenderness, warmth, dysfunction</td>
</tr>
<tr>
<td>II</td>
<td>Chronic tendinitis</td>
<td>Increased tendon degeneration and vascularity</td>
<td>Greater evidence of microtears, increased levels of collagen disorientation in tissue hypercellularity</td>
<td>Chronic pain w/ tenderness, increased dysfunction, person voluntarily unloads structure</td>
</tr>
<tr>
<td>III</td>
<td>Tendinosis</td>
<td>Intratendinous degeneration due to microtrauma, cellular/tissue aging; vascular compromise</td>
<td>Increased cellularity, neovascularization, focal necrosis, collagen disorganization and disorientation</td>
<td>Palpable tendon enlargement, swelling of tissues, increased dysfunction w/ or w/o pain, tendon sheath may be swollen</td>
</tr>
<tr>
<td>IV</td>
<td>Rupture</td>
<td>Tendon failure</td>
<td>Complete disruption of fibers</td>
<td>Weak and painful muscle testing, inability to move affected joint, + clinical tests for tendon disruption</td>
</tr>
</tbody>
</table>

Table 1: Nirschl's Stages of Tendinopathy*
group. Additionally, the OKC/CKC exercise group patients returned to this activity level two months earlier than the CKC exercise group. Mikkelsen et al\cite{91} concluded that the addition of OKC quadriceps strengthening (both concentric and eccentric) after ACL reconstruction leads not only to a significantly increased number of athletes returning to pre-injury sport level, but the speed at which they attained this level. The benefits of eccentric training is therefore demonstrated in both an OKC and CKC manner versus the traditional thought of OKC training being primarily concentric in nature. Controlled eccentric OKC training is safe and effective for the post ACL reconstruction patient.

Progressive eccentric exercise implemented post ACL reconstruction has demonstrated benefit with respect to volume and cross-sectional area of the quadriceps and gluteus maximus,\cite{86,87,89} superior short-term improvement in quadriceps torque,\cite{86,87,92} hopping distance and activity level,\cite{86,87} and knee flexion/extension range of movement during gait\cite{92} compared to a traditional post ACL reconstruction program. Improvements in quadriceps muscle strength and hopping distance also were significantly greater in the eccentric exercise group, as compared to the traditional exercise group, one year post surgery.\cite{87}

IMPLEMENTATION OF ECCENTRIC TRAINING AFTER ACL RECONSTRUCTION

The research regarding implementation of eccentric training during rehabilitation post ACL reconstruction is quite limited when compared to this type of training during rehabilitation of tendinopathy and muscle strains. As with any eccentric training program, systematic progression of training volume and intensity in the post ACL reconstruction patient is a necessity. Controlled eccentric training has been implemented safely as soon as three weeks post surgery in a modified CKC manner.\cite{88} This type of training was implemented on a mechanism similar to a modified ergometer.\cite{88} The authors of this review suggest the use of a total gym initially, with progression to a leg press machine, and eventually a squat rack. Both concentric and eccentric muscle training can be performed on each of these machines. Eccentric quadriceps contraction can be emphasized with training on these devices via increasing the knee flexion angle with the surgical lower extremity and straightening the leg (decreasing the knee flexion angle) with the non-surgical lower extremity. When implementing exercise using a squat rack in the later phases of rehabilitation, it is suggested to start with a Smith frame squat rack to limit potential transverse plane compensations on the part of the patient. The use of eccentric training on the non-involved lower extremity is also initially suggested since it has shown indication of being a useful mechanism in improving both the quadriceps muscle strength\cite{93} and the quadriceps accelerated reaction time in the surgical lower extremity.\cite{94} Table 2 details the specifics of the suggested implementation of a program as a guide to the eccentric component of a comprehensive strengthening program for the post ACL reconstruction patient. Ideally it is suggested that both OKC and CKC strengthening be employed in the rehabilitation program since OKC eccentric and concentric quadriceps strengthening has proven added benefit,\cite{91} yet sport related activities are primarily CKC. Although the focus of this commentary is detailing the benefits of eccentric training, it is the suggestion of the authors that this comprehensive approach, including both concentric and eccentric training be considered.

CONCLUSION

Eccentric exercise offers promise as an effective means to manage a host of common conditions encountered by the sports rehabilitation specialist. This promise is based upon both muscle and tendon physiology as they relate to performance. While evidence regarding the positive role of the varied uses of eccentrics in training, and prevention continues to emerge, it is but one component of a successful rehabilitation plan. Soft tissue mobilization, pain modulation, activity modification, patient education, biomechanical assessment, risk factor modification, and regional interdependence each play an integral role in the rehabilitation process. The challenge for the sports physical therapist is to clearly describe the ideal time to start eccentrics in the rehabilitation process, as well as how to manipulate training variables (load, volume, intensity, frequency) to provide a safe, yet progressive stimulus for eventual return to sport.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
<th>Intensity (Rate of Perceived Exertion)</th>
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</thead>
<tbody>
<tr>
<td>Phase I</td>
<td>Level I: CKC: Initiation of non-involved leg eccentric training for contralateral effect as early as day 2 post-operative unless restrictions or contraindicated.</td>
<td>Level I: Somewhat hard</td>
</tr>
<tr>
<td>(Weeks 0-3)</td>
<td>Level II: OKC: Approximately 6 weeks post-operatively strengthening initiated from 90°-45° flexion either isokinetically with low resistance (30°-90°/sec) or light weight (at mid shin) and repetitions in the range of 20-30. CKC: leg press-resistance of moderate level (single leg): eccentric lowering with involved leg, followed by concentric knee straightening with non-involved leg. ROM should be in short range to start (0-30°) and systematically increased no greater than 90°. Smith frame squat rack-bilateral squats with eccentric emphasis on involved leg and concentric phase assistance by non-involved leg as with leg press. Smith frame-reverse lunges can be initiated here if patient tolerates. Eccentric phase with involved leg; patient then locks bar into frame, and bar is raised to starting position using both legs.</td>
<td>Level I: progressed from very light-fairly light to somewhat hard-hard if tolerated</td>
</tr>
<tr>
<td>Phase II</td>
<td>Level I: CKC: Initiation of eccentric training on total gym at lowest level. Subject lowers themselves down in limited ROM (initially 0-40°) with surgery leg and raises themselves back up to full knee extension with assistance from non-involved leg. ROM (to 90°) and resistance level is progressively increased dependent on patient tolerance and ability.</td>
<td>Level I: progressed from very light-fairly light to somewhat hard-hard</td>
</tr>
<tr>
<td>(Weeks 3-12)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase III</td>
<td>Level I: CKC: leg press-moderate to heavy level resistance with technique as in phase II. ROM should be 0-90° unless otherwise contraindicated or not tolerated. Squat rack-bilateral squats as done in Smith frame in phase II. OKC: Eccentric isokinetic training at speeds of 30°-240° or with weight (at mid shin) with high repetition range (30-60). Level II: CKC: Squat rack-single leg lunges and reverse lunges progressed in intensity and ROM to 90° if not already achieved (Smith frame squat rack only if necessary)-eccentric emphasis only. Squat rack-single leg squats as done with bilateral squats in Level I.</td>
<td>Level I: progressed from somewhat hard to hard as tolerated.</td>
</tr>
</tbody>
</table>
REFERENCES


29. Thacker SB, J Gilchrist, D.F Stroup, and CD Kinzey Jr. The impact of stretching on sports injury risk:


ABSTRACT

The benefits and proposed physiological mechanisms of eccentric exercise have previously been elucidated and eccentric exercise has been used for well over seventy years. Traditionally, eccentric exercise has been used as a regular component of strength training. However, in recent years, eccentric exercise has been used in rehabilitation to manage a host of conditions. Of note, there is evidence in the literature supporting eccentric exercise for the rehabilitation of tendinopathies, muscle strains, and in anterior cruciate ligament (ACL) rehabilitation. The purpose of this Clinical Commentary is to discuss the physiologic mechanism of eccentric exercise as well as to review the literature regarding the utilization of eccentric training during rehabilitation. A secondary purpose of this commentary is to provide the reader with a framework for the implementation of eccentric training during rehabilitation of tendinopathies, muscle strains, and after ACL reconstruction.

Key Words: eccentric exercise, rehabilitation, tendinopathy, muscle strain, negative work, anterior cruciate ligament

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INTRODUCTION
Over approximately the last fifteen years, use of eccentric exercise in rehabilitation has increasingly gained attention in the literature as a specific training modality. That being said, the concept of eccentric exercise is not new. To the authors’ knowledge, the earliest investigation of eccentric versus concentric exercise was published in 1938.1 Eccentric exercise has been primarily described in the rehabilitation literature describing the management of tendinopathies. However, evidence is mounting to support its use in the treatment of muscle strains, with most of the rehabilitation literature relating to the use of eccentric training in rehabilitation after hamstring injuries. Finally, eccentric training has been used in recent years as a part of rehabilitation following ACL reconstruction. The purpose of this clinical commentary is to present the physiologic basis for eccentric exercise and to discuss the evidence in support of eccentric exercise in the management of patients recovering from tendinopathies, muscle strains, and ACL reconstructions. Additionally, suggested implementation of eccentric exercise in the management of these conditions will be highlighted. Although important to the clinician, the causes of these injuries as well as the mechanisms and origins of pain associated with these injuries are beyond the scope of this commentary. Further, other interventions used typically with these conditions such as stretching and modalities will not be discussed. It is important to note that although the focus of this commentary details the benefits of eccentric training, it is the authors’ suggestion that a comprehensive rehabilitation approach include both concentric and eccentric training. It is not the authors’ intent to advocate exclusive use of eccentric training, but rather to point out the investigated benefits of and utilization of eccentric exercise as a part of a comprehensive rehabilitation program.

PHYSIOLOGY OF ECCENTRIC EXERCISE
During voluntary contraction of a muscle, speed of contraction and ability to exert tension are inversely related. The faster a muscle contracts concentrically, the lower the tension it is able to generate.3 Tension in muscle fibers when lengthening is considerably greater than when muscle fibers are shortening.2 4 During negative work (eccentric exercise), the oxygen consumption rarely rises to more than twice the resting value.5-8 Previous studies have shown that when a muscle is eccentrically lengthened, the energy requirement falls substantially in comparison to concentric contractions because ATP breakdown and heat production are both slowed.8 10 Bigland-Ritchie et al11 found: 1) less muscle activity was required to maintain the same force during negative work, 2) fewer muscle fibers were required to exert a given force, and 3) there was a substantial reduction in oxygen uptake when fibers were eccentrically lengthened. Furthermore, with increased heat generation during concentric/positive work, there is a concurrent increase in cellular metabolism. Thus, more waste products will be generated with concentric work, potentially leading to chemical irritation of nerves and eventually pain. Abbott et al5 measured oxygen uptake in subjects during bicycle ergometry. Positive work (concentric exercise) resulted in more oxygen consumption than negative work. Abbott and others6 then performed a follow up study examining the relationship between oxygen consumption and work. Oxygen consumption was nearly three times larger at great force and low speed than at small force and high speed. The above studies show that eccentric exercise results in less oxygen consumption, greater force production, and less energy expenditure than concentric exercise.

TENDINOPATHY
Tendon injuries account for 30-50% of injuries in sports.12 Specifically, chronic problems caused by overuse of tendons result in 30% of all running-related injuries, and elbow tendon injuries can be as high as 40% in tennis players.13 Incidence of patellar tendinopathy is reported to be as high as 32% and 45% in basketball and volleyball players, respectively.14 Tendon pathologies not only lead to lost time and performance declines in sports, but also can result in long term damage to tendons that can affect daily function.

REVIEW OF LITERATURE: ECCENTRIC TRAINING IN TENDINOPATHY
Many studies recently have substantiated eccentric exercise as an effective treatment for tendinopathies. Eccentric training may be effective for tendinopathies based on work by Williams15 who found that
in most patients, both of which correlated with less pain, in a group of subjects with chronic Achilles tendinosis who were trained using the Alfredson et al\textsuperscript{16} eccentric calf protocol. Mahieu et al\textsuperscript{20} found that eccentric training of the plantar flexors resulted in positive changes to the mechanical properties of the plantar flexor muscle-tendon tissue including passive resistive torque, dorsiflexion range of motion, and stiffness.

Several authors have conducted studies that support the use of eccentric exercise in the treatment of a variety of tendinopathies. Jonsson and Alfredson\textsuperscript{21} studied athletes with jumpers knee (patellar tendinopathy) who were randomized into either an eccentric or concentric exercise group and treated for 12 weeks. At mean follow-up of 32 months, the eccentric exercise group was still satisfied subjectively and “sports active”, although it was not specifically stated whether they returned to sport or not. Subjects in the concentric exercise group had undergone surgery or sclerosing injections. In another study of elite volleyball players with patellar tendinopathy, Young et al\textsuperscript{22} found that subjects improved from baseline at 12 weeks and 12 months. In contrast, Visnes et al\textsuperscript{23} found no effect of eccentric training on jumper’s knee in volleyball players during the competitive season. The lack of results from eccentric training in this study may be due to the fact that athletes continued to participate in volleyball during the competitive season. Because rest is often advocated as a component of rehabilitation, failing to cease the aggravating activity may have perpetuated their injury and contributed to the lack of results.

Systematic reviews of literature by Wasielewski \& Kotsko\textsuperscript{24}, as well as Kingma et al\textsuperscript{25} examined the effects of eccentrics in reducing pain and improving strength in subjects with lower extremity tendinosis and chronic achilles tendinopathy, respectively. These reviews revealed that eccentric exercise may reduce pain and improve strength in patients with lower extremity tendinopathies, but whether it is better than other forms of rehabilitation has yet to be determined. Therefore, no definitive conclusions can be made regarding whether or not the performance of eccentric exercise alone is superior to concentric-eccentric training or concentric-minimized training.

Oxygen consumption is seven and a half times lower in tendons/ligaments than in skeletal muscle. A low metabolic rate and anaerobic energy generating capacity are needed to carry loads and maintain tension for long periods as is typical of tendons. However, the low metabolic rate results in slow healing after tendon injury. Based on data presented previously on the physiology of eccentric work requiring less oxygen consumption than concentric work, eccentric training may be ideally suited for the rehabilitation of tendinopathies.

In 1998, Alfredson\textsuperscript{16} performed, to the authors’ knowledge, the first study investigating the effects of eccentric exercise on diseased tendons. The protocol utilized has since been used in most studies on eccentric training. In a prospective study of 15 athletes with chronic achilles tendinosis, three sets of 15 repetitions of bent knee and straight knee calf raises were performed, twice a day, seven days per week over 12 weeks. Athletes were told to work through pain, only ceasing exercise if pain became disabling. Training load was increased in 5 kg increments with use of a backpack that allowed for the addition of the weight once training with bodyweight was pain free. All fifteen athletes returned to pre-injury levels of activity. Additionally, they had a significant decrease in pain with a significant increase in strength.

Positive changes in tissue structure and mechanical properties as a result of eccentric training have been previously described. Shalabi et al\textsuperscript{17} evaluated 25 patients with chronic achilles tendinopathy before and after an eccentric program using the Alfredson et al\textsuperscript{16} protocol. Subjects’ tendon volume and intratendinous signal were measured via magnetic resonance imaging (MRI). Eccentric training resulted in decreased tendon volume and decreased intratendinous signal, which correlated to improved pain and subjective performance. Reduction in fluid content within the tendon may suggest increased healthy collagen deposition. Langberg et al\textsuperscript{18} found that Type I collagen synthesis increased after eccentric training in a group of twelve soccer players with unilateral achilles tendinosis, offering a possible explanation for the mechanism of tendon healing. Ohberg et al\textsuperscript{19} also found a decrease in tendon thickness and normalized tendon structure measured by ultrasound.
IMPLEMENTATION OF ECCENTRICS IN REHABILITATION OF TENDINOPATHIES

Regardless of the involved tendon, load and volume of exercise should be progressed gradually and should be dictated by the amount of pain experienced by the athlete. Because the athlete is recovering from injury, the authors of this commentary advise that training load not be determined by a one repetition maximum (1 RM). Further, some of the exercises are for targeted muscle groups (elbow extensors for elbow injury) and determining a 1 RM is not practical or advised. The Alfredson et al16 protocol has been used in previous studies and appears to be a safe, effective method of implementing the eccentric training program for tendinopathies. Unfortunately, the Alfredson protocol was described for and used in the treatment of achilles tendinopathies and their exact recommendations may not be appropriate for all tendons or regions. The clinician may use the protocol for an example of volume and frequency of training, but in lieu of adding weights to a backpack, adding weights to a leg press or using various resistances of ankle weights and dumbbells would seem appropriate. For tendinopathies in the shoulder, elbow, or hand, increases by five-kilogram increments is likely inappropriate and resistances should be adjusted accordingly.

Curwin27 has previously proposed a method to determine training load in eccentric training for tendon injuries that is based on number of repetitions completed and the amount of pain experienced. One significant difference between Curwin’s and Alfredson’s programs is that the athlete performs both the concentric and eccentric portion of the exercise in Curwin’s program, with the eccentric portion being performed faster. Alfredson encouraged a slow, 3-4 second eccentric contraction. In Curwin’s protocol, they suggest that the athlete should experience pain and fatigue between 20 and 30 repetitions at a given load, when performing three sets of 10 repetitions. Their rationale for experiencing pain is based on the premise that exercise load should be determined by the tendon tolerance, which is indicated by pain experienced during the exercise. Curwin and Stanish determined empirically that pain felt before 20-30 repetitions would likely be accompanied by worsening of symptoms. Pain felt before that range is generally accompanied by worsening of symptoms and either load or speed is of contraction should be decreased. If there is no pain after 30 repetitions, the stimulus is inadequate. Either load or the speed of exercise performance should be increased, but not both simultaneously. Pain experienced during the exercise protocol should be similar to the pain experienced during the athlete’s functional activity with an acceptable, moderate increase from that point on in the program. During the first session, load is increased until symptoms appear. After a general warm-up (bike, upper body ergometer), athletes perform two 30 second stretches of the involved muscle group.

Based on the clinical experience of the authors and Ratamess and others,28 it is recommended that 6-12 repetitions over four sets be completed to emphasize strength in the muscle-tendon complex. The athletes use the load from the six repetition resistance and build up to twelve repetitions prior to increasing load again. Anecdotally, the authors have found this method to be progressive, yet safe, with less overall volume to help enhance recovery. Additionally, the authors advocate three to four sessions per week instead of every day. The authors propose that “heavy load” is a misnomer in the Alfredson et al16 study because the volume of exercise is rather high and the load is low given the amount of exercise that is tolerated by the athletes. Ultimately however, dosing must be based on tendon reactivity and patient response.

The authors suggest having the clinician or athlete perform the concentric portion of the exercise passively or with the assistance of the uninvolved limb during closed chain exercises, followed by having the athlete perform the eccentric portion of the exercise independently. Based on clinical experience, the authors propose that the concentric portion of the exercise can be attempted without assistance once non-sport activities, like walking and stair climbing, are pain free. As with eccentric exercise, progression of the concentric portion of exercise should involve a gradual increase. Once the concentric portion of exercise is pain free, the authors suggest that athletes can begin jogging or more sport specific activities. A progression from individual drills to team activities is a disciplined way to reintroduce an athlete to their chosen sport. If they have
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with increased time in competition and shortly after halftime.

Muscle strain injuries are thought to occur when muscles are actively lengthened to greater than resting lengths. The combination of rapid eccentric contraction with active muscle contraction elsewhere in the musculotendinous unit can produce mechanical strain leading to muscle injury. In ball sports, hamstring injury tends to occur when turning sharply or cutting, whereas in sprinting the injury occurs while running at full speed without a change of direction. Because of the biarticular nature of the hamstrings, they can be vulnerable to injury during running, cutting, and sprinting; all of which involve a combination of hip flexion and knee extension, which maximally lengthens the hamstring group. Hamstrings have to contract rapidly to generate a large amount of power. Several authors have suggested that most hamstring injuries occur during the late swing and early contact phases of running. Because the biceps femoris has greater lengthening and electrical activity during the late swing phase of running, it may be more susceptible to injury than the medial hamstrings. Kouloris and Connell found that biceps femoris strains accounted for 80% of the 170 hamstring injuries that occurred in athletes. Small et al found that reductions in eccentric strength occur during later stages of simulated soccer match play. Consequently, greater muscle strength imbalance between eccentric hamstring and concentric quadriceps strength has also been observed in later stages of match play or with fatigue.

HAMSTRING STRAIN
Most of the literature on muscle strains revolves around injuries to the hamstring muscle group, therefore, they will be the focus of this section. The reader is directed to the review by Hibbert et al on the effectiveness of eccentric strength training for the prevention of muscle strains.

Hamstring strains are among the most common injuries sustained by athletes. Hamstring muscle strains are currently the most common injury in professional soccer and they account for 29% of injuries in track and field sprinters. They are common in sports that require maximum sprinting, kicking, acceleration, and change of direction. The average amount of time lost from competition and training is 18 days, but has also been reported to vary between 8 and 25 days. Furthermore, athletes must deal with persistent symptoms and a likelihood of re-injury, found to be present in anywhere from 12-31% of those who sustain a hamstring strain. Highest risk of recurrence is within the first two weeks of returning to sport. Greig and Siegler performed an intermittent treadmill protocol to replicate soccer-specific fatigue. Peak isokinetic eccentric knee flexor strength was measured at three speeds at the end of a simulated (passive) halftime and at the end of the treadmill protocol. Eccentric hamstring strength decreased with increased work time and after the halftime interval. Athletes may therefore be at risk of injury with increased time in competition and shortly after halftime.

Sugiura et al performed a prospective study of elite sprinters to determine a relationship between strength and hamstring injury within 12 months of testing. This was the first study to examine the concentric and eccentric isokinetic strength of the hip extensors, quadriceps, and hamstrings that reflects their actions in late swing or early contact. Testing was performed on 30 male elite sprinters. Injuries occurred in six subjects. Eccentric weakness of the hamstrings at 60° per second was found to be a common factor among those who sustained injuries. Side to side comparison revealed that the injury always occurred on the weaker side. Similar findings were elucidated by Orchard et al who found that hamstring muscle injury was associated with low
hamstring-to-quadriceps ratio at 60° per second on the injured side and a low side-to-side peak torque at 60° per second in a group of Australian football players. Therefore, it may be advantageous to include eccentric training as part of either a training regimen or rehabilitation protocol to minimize asymmetries or to help maximize strength gains.

**REVIEW OF LITERATURE: ECCENTRIC TRAINING IN PREVENTION OF HAMSTRING STRAINS**

Small et al. investigated the effect of eccentric hamstring strengthening during soccer training. The objective was to evaluate if there was a difference in eccentric strength with fatigability and to see if eccentric training would attenuate the effects of fatigue. Sixteen semiprofessional soccer players completed a 90-minute simulated soccer game. At half time and at the conclusion of the game, the athletes performed isokinetic testing at 120° per second for the quadriceps and hamstrings. Two groups of subjects performed the “Nordic hamstring” eccentric exercise (Figure 1a, 1b) either during the cool-down or the warm-up period twice weekly during the 8-week intervention program. The group that performed the exercise in the cool down period showed significant increases in eccentric hamstring peak torque and the functional eccentric hamstring to concentric quadriceps ratio post-intervention compared to the warm-up group. Based on the results of this study, eccentric strength training conducted post-training significantly reduced the effects of fatigue. Therefore, performing eccentric training with fatigue may have a time-dependent beneficial effect.

Askling and others examined the relationship between eccentric training and subsequent injury in elite male soccer players. Thirty players were divided among two groups, one of which performed eccentric training in addition to the typical soccer team training 1-2x/week for 10 weeks, while the control group performed only the team training. Isokinetic hamstring strength and maximal running speed were measured in both groups before and after the training period. Injuries were monitored over 10 months. The eccentric training group had significantly fewer hamstring injuries (3/15) compared to the control group (10/15). In addition, the training group showed statistically significant improvements in strength and speed.

Arnason et al. compared “eccentric hamstring lowerers” (Nordic hamstring exercise) to contract-relax hamstring stretching with incidence and severity of hamstring strains in professional soccer players. Par-
Participants performed one of three interventions: warm up stretching performed independently with contract-relax stretching, partner-assisted contract-relax hamstring flexibility exercises, and eccentric hamstring exercises. The overall incidence of hamstring strains was 65% lower in the eccentric group. While incidence of hamstring injury was lower in the eccentric training group, injury severity and re-injury rates were not statistically significantly different.

Gabbe et al54 performed a randomized controlled trial that examined the relationship between eccentric strengthening and prevention of hamstring strains in 220 male football players in the Victorian Amateur Football Association. One group performed the “hamstring lowers” as previously described53 and the other performed stretching and range of motion exercises. Unfortunately, compliance was an issue in this study, but among players who completed at least two sessions, the incidence of hamstring strains in the eccentric group was 4% compared to 13% in the stretching and range of motion group. Brooks et al55 examined the effects of eccentric hamstring lowers and stretching on incidence and severity of hamstring strains in 546 professional rugby players. The intervention group was reported to display significantly lower incidence and severity of hamstring injury than the strengthening group and the conventional stretching/strengthening group.

Holcomb et al56 investigated whether a hamstring-emphasized resistance training program would improve isokinetic hamstring:quadriceps ratios in a group of 12 female NCAA soccer players. Subjects were tested before and after completing a six week training program with two randomly chosen specific exercises from a group of six exercises targeting the hamstrings. Subjects performed both the concentric and eccentric phases of the exercises. The hamstrings:quadriceps ratio was measured at 60, 180, and 240° per second. Six weeks of strength training emphasizing the hamstrings significantly increased the eccentric hamstring:concentric quadriceps ratio from below 1.0 to over 1.0. Eccentric hamstring:concentric quadriceps ratio has been advocated to be at least 1.0.57,58

While the above studies used eccentric training in healthy subjects or in the context of prevention of future injury, the data is nonetheless promising about the positive effects of eccentric training on strength, altering hamstring to quadriceps ratios, and preventing injury. Because of that, the clinician can surmise that the use of eccentric training as a part of the recovery after hamstring strains may lead to improved outcomes and decreased risk of future injury. It should be noted that the authors are not advocating the elimination of the concentric portion of an isotonic exercise, but rather increasing eccentric emphasis by assisting during concentric exercise or concentrically-minimized exercises.

IMPLEMENTATION OF ECCENTRICS TRAINING IN HAMSTRING STRAINS

Based on the literature presented on the varied outcomes related to eccentric training, it is evident that there may be promise in making eccentric training an integral part of the rehabilitation program after a hamstring strain. The authors of this commentary wish to focus on exercise interventions in lieu of isokinetic exercise interventions because access to isokinetic devices for a majority of clinicians is limited. The exercises subsequently discussed undeniably have a concentric component. As stated previously, the authors are not advocating elimination of the concentric portion of any exercise. It is generally accepted that it is virtually impossible and undesirable to eliminate the concentric portion entirely. However, the authors suggest that clinicians should have an increased awareness regarding how to design exercises to have a greater eccentric emphasis and should also consider how eccentric exercise should be a part of a systematic and progressive approach to training after injury to the hamstrings.

Comfort et al59 proposed a rehabilitation and conditioning continuum for hamstring rehabilitation. After the initial inflammatory phase resolves, initial goals are to restore range of motion and begin strengthening using hamstring-specific exercises that are primarily open kinetic chain and non-weight bearing. Once non-weight bearing exercises are tolerated, they suggest implementing low-velocity eccentric activities such as stiff leg dead lifts (Figure 2), eccentric hamstring lowers/Nordic hamstring exercise, and split squats (Figure 3a, 3b). The next phase involves higher velocity eccentric exercises that include plyometric and sport specific activities designed to increase hamstring torque and lower extremity power.
Examples include squat jumps, split jumps, bounding, and depth jumps. Finally, sport specific progressions should complete the program. Comfort et al\textsuperscript{59} suggest progressing from unidirectional linear movements to bidirectional and then multidirectional movements. Some of these exercises may include single leg bounding, backward skips, lateral hops, lateral bounding, and zigzag hops and bounding.

Brughelli and Cronin\textsuperscript{36} suggested a host of exercises in lieu of the “eccentric lowers/Nordic hamstring” exercise in the training of a non-injured athlete. They contend that while the “Nordic hamstring” may be a good exercise alternative, it is both bilateral and open chain. Because of this, one leg may be able to compensate for the involved limb. As stated previously, the hamstrings are a biarticular muscle and should be trained as such. Clark et al\textsuperscript{60} found that after four weeks of training with the Nordic hamstring exercise, vertical jump and peak torque of the hamstrings increased. Brughelli and Cronin\textsuperscript{36} propose that eccentric exercise interventions for reducing hamstring strains should include the following: high force, maximal muscle elongation, high velocity, multi-joint movements, closed-chain exercises, unilateral exercises, and easily implemented, cost-effective exercises.

**Figure 2.** Stiff leg deadlifts.

**Figure 3a, b.** Split squat and progression.
Isokinetic devices could be used for eccentric training, however are often cost-prohibitive, require proper patient training, and also require adequate space. Isokinetic exercise does not offer functional velocities for exercise training nor does it provide multi-joint, closed-chain options. In contrast, several exercises are advocated that require little equipment for effective implementation and fulfill the suggestions of Burghelli and Cronin. Some examples of these exercises include plyometric box jumps, eccentric backward steps (Figure 4), eccentric lunge drops (Figure 5a, 5b), eccentric forward pulls (Figure 6), single and double leg deadlifts, and in split stance deadlift ("good morning" exercise) with the load in front of the body, as opposed to a posterior load utilized during the traditional performance of this exercise (Figure 7a, 7b).
Heiderscheit and others\textsuperscript{38} recently commented on hamstring injuries and provided a structural framework for rehabilitation. Once the initial inflammatory phase has resolved, low intensity, pain free exercises involving the entire lower extremity and trunk are implemented to minimize atrophy and develop neuromuscular control of the lower extremities and trunk. Phase two exercises involve progression of intensity and range of motion based on patient tolerance. In stage two, eccentric exercises are initiated. Exercises are submaximal at the mid-length of the muscle and also include trunk stabilization exercises and agility training in the frontal and transverse planes. Finally, stage three exercises involve sport-specific exercises that involve quick direction changes, functional movement patterns, and eccentric exercises progressing to include end-range movement.

The authors of this commentary agree with Heiderscheit et al\textsuperscript{38} that initial phases of rehabilitation should focus on controlling pain, edema, and inflammation as well as tolerance of pain-free concentric exercises prior to initiation of eccentrics. Intuitively, eccentric exercises should be initiated in low to middle ranges of motion in order to limit the risk of further injury.

Walking lunges, multi-directional step ups, split squats, stiff leg dead lifts, and “modified good mornings” should be implemented within pain free range of motion. Additionally, the authors of this commentary recommend doing the Nordic hamstring/eccentric lowers with elastic band assistance (Figure 8) in rehabilitation, and the previously described technique (Figure 1a, 1b) would be a progression. By using a heavy-resistance band, the recovering athlete has the elasticity of the band to assist in both the concentric and eccentric portions of the exercise. As the athlete tolerates this exercise and completes it throughout the full range of motion, the band can be eliminated.

The authors suggest agility ladder drills and shuffling can be used as either an “active recovery” or as an active warm-up. As the athlete continues to tolerate increased range of motion during exercises, load should be increased with a concomitant decrease in volume. For hamstring strengthening, the authors of this manuscript refer the reader to the American College of Sports Medicine’s Position Statement by Ratamess and colleagues\textsuperscript{28} for progression of resistance exercise. The authors propose increasing speed of performance to more closely replicate

\textbf{Figure 7a, b.} Split stance Zercher also called the “good morning” exercise. The subject is in a split stance position with the weight placed anteriorly to increase the lever arm on the hamstrings. The subject then leans forward through flexion at the hip.
sport demands. Athletes can perform exercises in a given time frame (i.e. continuous for 35-45 seconds for a hockey player) or with modifications in work: rest ratios (i.e. football player performing multiple 7-second exercise bouts with 25-35 second rest) to more closely mimic the metabolic demands of their sport. Once multi-directional closed and open chain exercises are tolerated, the athlete’s program should be progressed to require the athlete to run up hill in order to improve stride length, and run downhill in order to improve stride frequency as well as to condition the athlete to tolerate frequent, rapid shifts between concentric and eccentric movements. Additionally, the authors propose performing eccentric hamstring exercises at the close of the training session when the athlete is fatigued. Previous researchers have found that strength production in the hamstrings declines with fatigue, therefore training when fatigued may provide protection against injury.

**ANTERIOR CRUCIATE LIGAMENT (ACL) RECONSTRUCTION**

Injury to the ACL is a common and significant knee injury, potentially resulting in limitations in range-of-motion, degenerative changes of the knee joint and muscular atrophy. Muscular atrophy greater than 20% and strength loss exceeding 30% have been demonstrated strength persisting for several years after surgery. Hamstring and gracilis muscle volume deficits of 10% and 30% were found post ACL reconstruction with autologous semitendinosus-gracilis graft. Amelioration of these deficits continues to be a clinical challenge requiring systematically progressed strengthening protocols that encompass all components of lower extremity function.

High intensity and accelerated intervention programs have long been suggested as optimal and reported as safe following ACL reconstruction. LaStayo et al suggested that eccentric training for the quadriceps was more effective in recovery of strength deficits post ACL reconstruction due to this type of training promoting greater changes in neural activation and muscle hypertrophy. Investigation of higher intensity rehabilitation training (producing increasingly greater strain on the ACL graft) versus a program producing minimal strain on the graft found no differences in knee laxity, activity level, function, and patient satisfaction up to 2 years postoperatively.

Although it was concluded that these higher intensity programs were safe, Beynnon et al emphasized use of caution with increasing the frequency and magnitude of quadriceps activity due to concern of increasing anterior knee laxity. Additionally, it has been demonstrated that when applied gradually and progressively, an eccentric (or negative-work) exercise training for the quadriceps is safe for these patients and can be tolerated without damage. Eccentric knee extensor training was purported to be essential for restoration of the functional capacity of the ACL reconstructed knee due to findings of significantly larger concentric and eccentric peak torque deficiencies in the knee extensors as compared to the knee flexors.

Mikkelsen et al compared a closed kinetic chain (CKC) training program versus training with CKC...
and open kinetic chain (OKC) exercise starting at 6 weeks post ACL reconstruction. Anterior knee laxity (KT-1000 arthrometer), isokinetic concentric and eccentric quadriceps and hamstring muscle torque (isokinetic dynamometry before and six months after surgery), and return to preinjury sports level (questionnaire at an average of 31 months post surgery) were measured in 44 patients with unilateral ACL reconstruction. No significant differences in anterior knee laxity were noted between the groups at six months post surgery. Those performing OKC in addition to CKC increased their quadriceps torque to a significantly greater degree than those performing only CKC exercises. No significant differences were noted between groups for hamstring muscle torque. The number of patients returning to pre-injury sports level participation was greater in the OKC/CKC exercise group than the CKC exercise only.

| Table 1: Nirschl's Stages of Tendinopathy |
|---|---|---|---|---|
| Stage | Diagnosis | Macroscopic Pathology | Histologic Findings | Clinical Signs |
| 0 | Healthy | No inflammation | Organized collagen, absent blood cells | Firm tendon, not painful, absent swelling, normal temperature |
| I | Acute tendinitis | Symptomatic tendon degeneration, increased cellularity, vascular disruption, inflammation of paratenon | Degenerative changes w/ microtears, inflammatory cells in paratenon; focal collagen disorientation | Acute swelling, pain, local tenderness, warmth, dysfunction |
| II | Chronic tendinitis | Increased tendon degeneration and vascularity | Greater evidence of microtears, increased levels of collagen disorientation in tissue hypercellularity | Chronic pain w/ tenderness, increased dysfunction, person voluntarily unloads structure |
| III | Tendinosis | Intratendinous degeneration due to microtrauma, cellular/tissue aging; vascular compromise | Increased cellularity, neovascularization, focal necrosis, collagen disorganization and disorientation | Palpable tendon enlargement, swelling of tissues, increased dysfunction w/ or w/o pain, tendon sheath may be swollen |
| IV | Rupture | Tendon failure | Complete disruption of fibers | Weak and painful muscle testing, inability to move affected joint, + clinical tests for tendon disruption |
group. Additionally, the OKC/CKC exercise group patients returned to this activity level two months earlier than the CKC exercise group. Mikkelsen et al.\textsuperscript{91} concluded that the addition of OKC quadriceps strengthening (both concentric and eccentric) after ACL reconstruction leads not only to a significantly increased number of athletes returning to pre-injury sport level, but the speed at which they attained this level. The benefits of eccentric training is therefore demonstrated in both an OKC and CKC manner versus the traditional thought of OKC training being primarily concentric in nature. Controlled eccentric OKC training is safe and effective for the post ACL reconstruction patient.

Progressive eccentric exercise implemented post ACL reconstruction has demonstrated benefit with respect to volume and cross-sectional area of the quadriceps and gluteus maximus,\textsuperscript{86,87,99} superior short-term improvement in quadriceps torque,\textsuperscript{86,87,92} hopping distance and activity level,\textsuperscript{86,87} and knee flexion/extension range of movement during gait\textsuperscript{92} compared to a traditional post ACL reconstruction program. Improvements in quadriceps muscle strength and hopping distance also were significantly greater in the eccentric exercise group, as compared to the traditional exercise group, one year post surgery.\textsuperscript{87}

**IMPLEMENTATION OF ECCENTRIC TRAINING AFTER ACL RECONSTRUCTION**

The research regarding implementation of eccentric training during rehabilitation post ACL reconstruction is quite limited when compared to this type of training during rehabilitation of tendinopathy and muscle strains. As with any eccentric training program, systematic progression of training volume and intensity in the post ACL reconstruction patient is a necessity. Controlled eccentric training has been implemented safely as soon as three weeks post surgery in a modified CKC manner.\textsuperscript{88} This type of training was implemented on a mechanism similar to a modified ergometer.\textsuperscript{88} The authors of this review suggest the use of a total gym initially, with progression to a leg press machine, and eventually a squat rack. Both concentric and eccentric muscle training can be performed on each of these machines. Eccentric quadriceps contraction can be emphasized with training on these devices via increasing the knee flexion angle with the surgical lower extremity and straightening the leg (decreasing the knee flexion angle) with the non-surgical lower extremity. When implementing exercise using a squat rack in the later phases of rehabilitation, it is suggested to start with a Smith frame squat rack to limit potential transverse plane compensations on the part of the patient. The use of eccentric training on the non-involved lower extremity is also initially suggested since it has shown indication of being a useful mechanism in improving both the quadriceps muscle strength\textsuperscript{93} and the quadriceps accelerated reaction time in the surgical lower extremity.\textsuperscript{94} Table 2 details the specifics of the suggested implementation of a program as a guide to the eccentric component of a comprehensive strengthening program for the post ACL reconstruction patient. Ideally it is suggested that both OKC and CKC strengthening be employed in the rehabilitation program since OKC eccentric and concentric quadriceps strengthening has proven added benefit,\textsuperscript{91} yet sport related activities are primarily CKC. Although the focus of this commentary is detailing the benefits of eccentric training, it is the suggestion of the authors that this comprehensive approach, including both concentric and eccentric training be considered.

**CONCLUSION**

Eccentric exercise offers promise as an effective means to manage a host of common conditions encountered by the sports rehabilitation specialist. This promise is based upon both muscle and tendon physiology as they relate to performance. While evidence regarding the positive role of the varied uses of eccentrics in training, and prevention continues to emerge, it is but one component of a successful rehabilitation plan. Soft tissue mobilization, pain modulation, activity modification, patient education, biomechanical assessment, risk factor modification, and regional interdependence each play an integral role in the rehabilitation process. The challenge for the sports physical therapist is to clearly describe the ideal time to start eccentrics in the rehabilitation process, as well as how to manipulate training variables (load, volume, intensity, frequency) to provide a safe, yet progressive stimulus for eventual return to sport.
<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
<th>Intensity (Rate of Perceived Exertion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase I</td>
<td>Level I: CKC: Initiation of non-involved leg eccentric training for contralateral effect as early as day 2 post-operative unless restrictions or contraindicated.</td>
<td>Level I: Somewhat hard</td>
</tr>
<tr>
<td>(Weeks 0-3)</td>
<td></td>
<td></td>
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<tr>
<td>Phase II</td>
<td>Level I: CKC: Initiation of eccentric training on total gym at lowest level. Subject lowers themselves down in limited ROM (initially 0-40°) with surgery leg and raises themselves back up to full knee extension with assistance from non-involved leg. ROM (to 90°) and resistance level is progressively increased dependent on patient tolerance and ability. Level II: OKC: Approximately 6 weeks post-operatively strengthening initiated from 90° - 45° flexion either isokinetically with low resistance (30°-90°/sec) or light weight (at mid shin) and repetitions in the range of 20-30. CKC: leg press-resistance of moderate level (single leg): eccentric lowering with involved leg, followed by concentric knee straightening with non-involved leg. ROM should be in short range to start (0-30°) and systematically increased no greater than 90°. Smith frame squat rack-bilateral squats with eccentric emphasis on involved leg and concentric phase assistance by non-involved leg as with leg press. Smith frame-reverse lunges can be initiated here if patient tolerates. Eccentric phase with involved leg; patient then locks bar into frame, and bar is raised to starting position using both legs.</td>
<td>Level I: progressed from very light-fairly light-somewhat hard-hard Level II: progressed from very, very light-fairly light-somewhat hard-hard if tolerated</td>
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<tr>
<td>(Weeks 3-12)</td>
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<tr>
<td>Phase III</td>
<td>Level I: CKC: leg press-moderate to heavy level resistance with technique as in phase II. ROM should be 0-90° unless otherwise contraindicated or not tolerated.</td>
<td>Level I: progressed from somewhat hard to hard as tolerated.</td>
</tr>
<tr>
<td>(Weeks 12+)</td>
<td>Squat rack-bilateral squats as done in Smith frame in phase II. OKC: Eccentric isokinetic training at speeds of 30°-240° or with weight (at mid shin) with high repetition range (30-60). Level II: CKC: Squat rack-single leg lunges and reverse lunges progressed in intensity and ROM to 90° if not already achieved (Smith frame squat rack only if necessary)-eccentric emphasis only. Squat rack-single leg squats as done with bilateral squats in Level I.</td>
<td>Level II: progressed from somewhat hard to hard as tolerated.</td>
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REFERENCES

29. Thacker SB, J Gilchrist, D.F Stroup, and CD Kinzey Jr. The impact of stretching on sports injury risk:


CLINICAL SUGGESTION

UTILIZATION OF SONOGRAPHY AND A STRESS DEVICE IN THE ASSESSMENT OF PARTIAL TEARS OF THE ULNAR COLLATERAL LIGAMENT IN THROWERS

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ABSTRACT

The non-invasive assessment of medial elbow pain in throwers can be challenging. Valgus stress transmitted to the elbow during the late cocking and acceleration phases of the throwing motion can result in injury to the medial ligamentous structures of the elbow, bony surfaces, and common tendon of the forearm flexors. The utilization of musculoskeletal (MSK) ultrasound in combination with the Telos Stress Device (TSD) (Austin & Associates Fallston, MD) can be an alternate quick assessment when radiography is not be available.

Key Words: Musculoskeletal Ultrasound Imaging, Ulnar Collateral Ligament, Telos Stress device

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INTRODUCTION

The non-invasive assessment of medial elbow pain in throwers can be challenging. Valgus stress transmitted to the elbow during the late cocking and acceleration phases of the throwing motion can result in injury to the medial ligamentous structures of the elbow, bony structures, and other soft tissues including the common flexor tendon and ulnar nerve.1,2

Baseball players and other overhead throwing athletes can experience vague pain as well as clinically undetectable joint laxity along the medial aspect of the elbow. As the injury progresses, a tear of the ulnar collateral ligament (UCL) will manifest itself as reduced velocity control evident during pitching or throwing.3

Physical examination frequently includes palpation, valgus stress testing, and grip strength testing. When positive, these examinations may be suggestive of but not definitive of a UCL tear. Incomplete tears are often tender upon palpation, but may not demonstrate significant distraction or gapping on valgus stress testing. Stress radiography, Magnetic Resonance Imaging (MRI) and Computer Tomography Arthrography (CTA) remain the gold standard imaging tools for evaluating medial elbow pain and instability.4 Timmerman et al, prospectively studied twenty-five baseball players with medial elbow pain and found that each of these diagnostic tools were accurate in identifying both complete and partial undersurface UCL tears.4

Musculoskeletal (MSK) ultrasound imaging has emerged as an additional diagnostic tool than can be used to assess medial elbow pain and laxity in baseball players.5,7,8 Sasaki et al (2002) was one of the first groups to utilize this form of imaging when they assessed medial elbow instability in baseball players aged 19 to 24 years.6 The authors were able to detect significant medial elbow joint gapping of the throwing arm, as well as structural changes to the visualized tissue. These authors’ technique involved a gravity valgus stress applied when the elbow was placed at 90 degrees of flexion.

The anterior bundle of the UCL is the major dynamic restraint resisting valgus stress of the elbow during the throwing motion. The anterior bundle of the UCL is commonly injured in throwers7 and diagnosis of UCL tears is often difficult, requiring several imaging modalities to assist in confirming the diagnosis. Nazarian et al (2003) used dynamic MSK to reveal abnormalities of the anterior band of the UCL in asymptomatic major league baseball players.7 They found that dynamic MSK ultrasound provided a rapid option for evaluating the UCL in professional baseball pitchers. In pitching arms, the anterior band is thicker and more likely to have hypoechoic foci and/or calcifications, and demonstrates more laxity with valgus stress. Harada et al8 assessed one hundred and fifty youth baseball players and found that ultrasonography proved effective in detecting medial epicondylar fragmentation, ulnar collateral injuries, and osteochondritis dissecans of the capitellum among young players before they became symptomatic.

DESCRIPTION OF THE DEVICE

Authors have utilized a stress radiography device in order to objectively evaluate medial collateral ligament laxity in throwing athletes. Rijke et al.5 concluded that stress radiography of the UCL with the use of the Telos GA–II E Stress Device (TSD) (Austin & Associates Fallston, MD) enabled accurate diagnosis of large tears and elucidated the distinction between these tears and small tears. Ellenbecker et al1 utilized stress radiography performed using the TSD to examine the elbow of forty uninjured professional baseball pitchers. They used the TSD to determine differences in medial ligament laxity between the players' dominant and non-dominant arms. In both these studies employing the TSD, stress radiography proved a non-invasive technique to assess medial elbow pain in the throwing athlete.8

The TSD is used to apply objectively quantifiable stress examinations of the ankle, knee, elbow, and shoulder. This device allows the operator to provide a defined amount of pressure or force to the joint during testing by observing the force on an illuminated LED readout.

MSK ultrasound provides real time soft tissue images using reflected sound waves. This device is both
The patient’s wrist is supinated and secured between two roller bars. The fingers and thumb grasp the third roller bar. The ulnar aspect of the distal forearm is locked against one of the upright counter bearing bars. A counter force is applied to the radial side of elbow by a screw-threaded device with a diode digital light-measuring device. Before adding stress, an initial sonogram is taken to provide a baseline. The screw shaft device is then used to apply a valgus force. Sequential sonograms are then taken at 10 and 15 kilo-pascal units of force (measured by the diode digital light-measuring device).

The ultrasound transducer is placed longitudinally to forearm and proximally over medial epicondyle. Note that the transducer is parallel with the forearm. This provides proper coronal imaging over medial elbow demonstrating the anterior band of the UCL, common forearm flexors tendon, medial epicondyle (ME), trochlea (T), and ulna (U).

The location of the common flexor tendon origin is identifiable on the medial epicondyle. Distal and deep to the common flexor tendon origin, is the triangular shape of the UCL that can be viewed; (ME)
the medial epicondyle; (T) the trochlea; and (U) the ulna.

Constant and progressively graded forces applied to the medial structures allows for examination of regions of UCL partial disruption that may otherwise have been overlooked. The arrow demonstrates a small hypoechoic area in the proximal ligament while the arrowheads illustrate mild widening of the elbow joint compatible with ligamentous injury.

Measurements can be taken at the ulnohumeral joint to assess amount of joint space widening within the joint. Comparison studies of both elbows must be taken. Studies using the TSD during stress radiographs have reported findings of gap joint opening greater that 0.2mm to be suggestive of a partial tear.5

Figure 4. Telos Stress Device Procedure:
1. At 0 stress an initial sonogram is taken to provide a baseline
2. The screw shaft device applies a valgus stress.
3. Sequential sonograms are then taken 10 and 15 kilo-pascals of stress (as read on the diode digital light-measuring device).

Figure 5. Ultrasound 12 MHZ frequency transducer is placed in a longitudinal plane on the medial side of the elbow. Note that the transducer is parallel with the forearm.

Figure 6. Ultrasound image of medial elbow without imposed stress. Note the origin of the common flexor tendon (F), the epicondyle (E), the trochlea (T), and ulna (U) with the UCL identifiable between the two arrows.

Figure 7. Example of a diagnostic ultrasound image of the medial elbow at 9 mpa of force. The arrowheads demonstrate small hypoechoic areas that correlate to a tear within the anterior band of the UCL. Arrow is pointing to the anterior band of UCL. Common flexor tendon (F), medial epicondyle (me) are identified.
coronoid process serve as excellent bony acoustic landmarks that enable MSK ultrasound the capability of viewing the UCL. Careful attention must be paid to establish the proper angle for transducer placement. The transducer should be perpendicular to the ligament in order to avoid anisotropy. Anisotropy is defined as a variance in the echogenicity of the scan as a result of a transducer being placed greater or lesser than 90 degrees perpendicular to the structure being examined, thereby producing an artifact.10

CONCLUSION
Due to rapidly evolving technology, MSK ultrasound as well as the stress device can allow direct visualization of soft tissue structures without exposing an athlete to undue radiation, thus making it an effective and safe assessment tool. When used at the elbow coupled with the TSD, sonographic changes such as excessive asymmetric joint widening, ligamentous thickening, hypoechoic defects, and ligament calcification can be described and correlated with clinical and physical findings. In the current era of medical reform, cost containment is an issue when choosing diagnostic tools. In studies of the medicare population, the projected cost savings of substituting musculoskeletal ultrasound for MRI would be more than $6.9 billion in the period between 2006–2020.11 Large cost savings could help influence physicians and insurance providers regarding the benefit of using this diagnostic imaging option over MRI. The limitations of MSK ultrasound imaging are minor; and they include operator dependency and a learning curve. Those who use MSK ultrasound must be properly trained to achieve valid and reliable test results. Certification training in the use of musculoskeletal ultrasound as a diagnostic tool is currently lacking, but courses are being developed to provide health care providers with the opportunity to learn proper assessment techniques and earn valid certifications.

REFERENCES

DISCUSSION
The superficial location of the UCL of the elbow makes this structure well suited for ultrasound evaluation. Ultrasonography can be used to assess both the integrity of the ligament and the widening of the medial joint space when valgus force is applied.6,7,8,9

The key to a successful exam is a well-positioned transducer on a comfortably seated patient. According to Nazarian et al., the medial epicondyle and the

Figure 8. Example ultrasonographic measurement of the ulnohumeral joint to assess amount of opening within the joint under valgus loading.

Figure 9. Radiograph demonstrating Telos Stress Device placement and valgus stress being applied to the elbow.


ABSTRACT

Subacromial impingement is a frequent and painful condition among athletes, particularly those involved in overhead sports such as baseball and swimming. There are generally two types of subacromial impingement: structural and functional. While structural impingement is caused by a physical loss of area in the subacromial space due to bony growth or inflammation, functional impingement is a relative loss of subacromial space secondary to altered scapulohumeral mechanics resulting from glenohumeral instability and muscle imbalance. The purpose of this review is to describe the role of muscle imbalance in subacromial impingement in order to guide sports physical therapy evaluation and interventions.

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INTRODUCTION
According to the late neurologist Vladimir Janda MD, there are 2 approaches to classification of musculoskeletal pathologies: structural and functional.1 The structural approach focuses on actual damage to musculoskeletal structures such as rotator cuff tendinitis or a ligament injury. The functional approach examines factors that contribute to structural lesions. This approach is most useful for physical therapy management of chronic ‘dysfunctions’ such as persistent joint pain and tendonitis.

Shoulder impingement accounts for 44 to 65% of shoulder complaints during physician visits.2 It was first described by Neer,4 shoulder impingement has been classified into two main categories: structural and functional. Subacromial impingement can be caused by narrowing of the subacromial space (SAS) resulting from a reduction in the space due to bony growth or soft-tissue inflammation, (“structural”) or superior migration of the humeral head caused by weakness and/or muscle imbalance (“functional”).5-8 It is possible that some subacromial impingement results from a combination of both structural and functional factors.

Subacromial impingement occurs when the structures in the SAS (rotator cuff, biceps tendon long head, and subacromial bursa) become compressed and inflamed under the coracoacromial ligament.9 The suprasinatus tendon in particular is at highest risk for irritation and subsequent injury because it is the most likely to contact the acromion when the humerus is abducted to 90° and internally rotated 45°.10

Patients with impingement have significantly less (~68%, p < .05) SAS during shoulder elevation compared to the asymptomatic side when measured using MR imaging,11 even though their SAS is not significantly different from healthy shoulders in the resting anatomical position.12 When compared to normal subjects, patients with impingement demonstrate more proximal translation of the humeral head during abduction, thus reducing the SAS.6, 13

Functional impingement is related to glenohumeral instability14 and is sometimes described as “functional instability,” occurring mostly in overhead athletes less than 35 years of age.15 The act of throwing may cause tissues below the coracoacromial arch to be subjected to subtle microtrauma, leading to inflammation and tendinitis.16-17

The shoulder complex relies on muscles to provide dynamic stability during its large range of mobility. Proper balance of the muscles surrounding the shoulder complex is also necessary for flexibility and strength; a deficit in flexibility or strength in an agonistic muscle must be compensated for by the antagonistic muscle, leading to dysfunction. These muscular imbalances lead to changes in arthrokinematics and movement impairments, which may ultimately cause structural damage. Dr. Janda suggested that subacromial impingement results from a characteristic pattern of muscle imbalance including weakness of the lower and middle trapezius, serratus anterior, infraspinatus, and deltoid, coupled with tightness of the upper trapezius, pectorals and levator scapula.1 This pattern is often referred to as part of Janda’s “Upper Crossed Syndrome.” (See Figure 1)

While structural impingement sometimes requires surgery to alleviate pain, functional instability requires the implementation of precise therapeutic exercises.

**Figure 1. Janda’s Upper Crossed Syndrome. Reprinted, with permission, from Page et al, 2010, Assessment and Treatment of Muscle Imbalance: The Janda Approach (Champaign, IL: Human Kinetics).**
with the goal of restoration of normal neuromuscular function. It is important for clinicians to understand the pathomechanics of functional impingement in order to guide appropriate examination, assessment, and intervention, as well as to consider prevention. The purpose of this clinical suggestion is to describe muscle imbalances associated with functional impingement in overhead athletes and to offer suggestions to guide intervention choices and prevention strategies.

PATHOMECHANICS OF MUSCLE IMBALANCE IN SUBACROMIAL IMPINGEMENT

Muscle tightness has been implicated in subacromial impingement. In particular, during elevation, anterior shoulder girdle muscle tension may affect the tension on the leading edge of the coracoacromial ligament, predisposing it to tightness ultimately leading to structural impingement. Tightness of the pectoralis major creates an anterior force on the glenohumeral joint with a consequent decrease in stability. A tight pectoralis minor limits scapular upward rotation, external rotation, and posterior tilt, thereby reducing SAS. This alteration in scapular kinematics occurs in three separate planes of movement and differs from scapular kinematics of those with normal muscle length.

Imbalances in glenohumeral rotation range of motion may also contribute to altered shoulder kinematics. Specifically, excessive external rotation leads to increased anterior and inferior translation of the humerus, leading to anterior instability. In contrast, a lack of external rotation due to anterior muscular tightness alters the scapulohumeral rhythm and decreases posterior scapular tilt. Posterior capsular tightness, often demonstrated by a loss of internal rotation, may lead to more superior and anterior translation of the humeral head. This loss of internal rotation is known as glenohumeral internal rotation deficit, or “GIRD,” and is defined as a loss of internal rotation greater than or equal to 20° compared to the contralateral side. GIRD is a relatively new concept in the literature that requires more research regarding its incidence and effects in normal, athletic, and injured populations. Recent evidence suggests that overhead athletes with impingement often display signs and symptoms of GIRD.

Imbalances or deficits in muscular strength and activation levels can lead to functional impingement. Both glenohumeral and scapulothoracic muscle imbalances can contribute to shoulder complex dysfunction. The pathomechanics of functional impingement may involve one or both of the shoulder force couples: deltoid/rotator cuff and scapular rotators. (Figures 2-3) Because of the lack of prospective studies, researchers have not determined whether muscle imbalance is a contributor to or result of impingement.

GLENOHUMERAL IMBALANCES

Alterations in deltoïd and rotator cuff co-activation and rotator cuff imbalances have been described in patients with impingement. The deltoïd plays an important role in the pathomechanics of impingement due to its ability to offer upwardly directed force which must be balanced by the synchronous function of the rotator cuff musculature. Muscle imbalances within the deltoïd and rotator cuff force couple can cause compression within the SAS. The deltoïd has been found to be atrophied and infiltrated with
connective tissue in patients with shoulder impingement, and it exhibits lower levels of EMG activation in patients with impingement. While it is assumed that these effects on the deltoid are caused by impingement, it is unclear if the deltoid pathology precedes or is a result of impingement.

The rotator cuff is important in maintaining normal humeral head position in the glenoid during elevation (flexion and abduction) movements. The compressive forces of the rotator cuff stabilize the humerus against the glenoid, thereby providing dynamic stabilization of the glenohumeral joint. Weakness of the infraspinatus reduces this compressive force, promoting instability. This instability may lead to functional impingement.

When the dynamic stabilizing forces of the rotator cuff are removed from the glenohumeral joint in a cadaver model, there is a significant increase in superior and anterior migration of the humeral head during elevation, which would lead to impingement. Downward compressive forces of the inferior rotator cuff are necessary to neutralize the upwardly directed shear forces of the deltoid. Without rotator cuff stabilization in cadaveric models, the humeral head migrated 1.7 mm vs. 0.7 mm with rotator cuff stabilization at 60° of abduction, and 2.1 mm vs. 1.4 mm at 90° of abduction. Clearly, while cadaveric models do not accurately reflect the effect of dynamic neuromuscular activation (muscle activation and timing) of glenohumeral and scapulothoracic muscles during glenohumeral kinematics, they may offer some insight into the role of the rotator cuff.

Decreased rotator cuff EMG activity may also contribute to humeral head superior translation during early abduction, leading to impingement. Experimentally-induced fatigue of the rotator cuff leads to superior migration of the humeral head at the initiation of abduction, however, the effects of fatigue experienced after actually participating in an activity (such as repeated throwing) have not been investigated. Since these two studies only assessed scapular plane elevation, it is possible that other muscles may compensate for upward migration of the humeral head during functional activities that occur in planes other than the scapular plane. Few studies have assessed simultaneous rotator cuff EMG and glenohumeral kinematics in patients with impingement, leaving many questions unanswered regarding the exact pathomechanics of impingement.

SCAPULOTHORACIC IMBALANCES

Scapular rotation force couple imbalance leads to altered muscular activation patterns. When studying patients with impingement, most researchers describe an increase in upper trapezius EMG activation coupled with a decrease in activation of the middle trapezius, lower trapezius, and the serratus anterior. Ludewig and Cook hypothesized that the increased lower trapezius activation was an attempt to compensate for decreased serratus anterior activation. In contrast, other researchers have reported increased EMG activation in both the upper and lower trapezius in patients with impingement when compared to normal subjects. Ludewig and Cook hypothesized that the increased lower trapezius activation was an attempt to compensate for decreased serratus anterior activation. Interestingly, Lin et al studied subjects with various types of shoulder dysfunction and found decreased serratus anterior activity and increased upper trapezius activity without a change in lower trapezius activity when compared to normals.
have a significantly higher upper trapezius activation compared to normal subjects, a significant decrease in lower and middle trapezius activation, and altered trapezius muscle balance (See Table 1).

Overhead athletes with impingement have delayed onset of middle and lower trapezius fibers in response to a sudden downward movement. If the lower trapezius reacts too slowly when compared to the upper trapezius, the upper trapezius may become overactive, leading to scapular elevation rather than upward rotation. Freestyle swimmers with impingement are reported to have increased variability in timing of the onset of scapular rotators compared to healthy swimmers. These alterations in activation patterns are often seen bilaterally in patients with chronic tendinosis, supporting a neuromuscular mechanism. Since both painful and non-painful shoulders exhibit altered activation patterns, it is possible that the dysfunction is related to a faulty motor program within the central nervous system (CNS).

**CONCLUSIONS**

In summary, functional impingement may be associated with muscle imbalance; therefore, careful examination of flexibility and strength of important muscles about the shoulder complex is vital to understanding the root cause of impingement and prescribing effective treatment. Janda’s approach to muscle imbalance suggests a possible neuromuscular component to functional impingement due to the predisposition of certain muscles to be tight or

<table>
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<th>Patient Group</th>
<th>Upper Trap Activation</th>
<th>Lower Trap Activation</th>
<th>UT:LT ratio</th>
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<tr>
<td>Involved side (impingement)</td>
<td>95% MVIC</td>
<td>48% MVIC</td>
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<td>Involved side (control)</td>
<td>73% MVIC</td>
<td>62% MVIC</td>
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<tr>
<td>Uninvolved side (impingement)</td>
<td>74% MVIC</td>
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<tr>
<td>Involved side (control)</td>
<td>74% MVIC</td>
<td>62% MVIC</td>
<td>1.36</td>
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weak. The literature substantiates that imbalances in the glenohumeral and scapulothoracic musculature are present in patients with subacromial impingement.

Most believe that functional impingement is best managed with conservative treatment. While structural impingement sometimes requires surgical intervention, surgery for functional impingement may make patients worse. Successful treatment of functional impingement related to muscle imbalance is often accomplished by addressing the cause of the problem rather than symptomatic treatment of the pain. By understanding muscle imbalances associated with functional impingement, physical therapists can prescribe appropriate exercises for both treatment and prevention.

REFERENCES


ABSTRACT

An integral part of the responsibilities of the sports physical therapist is emergency care that is provided on the sidelines and courtside during athletic events. Often times, the sports physical therapist is the “most medical” individual present at athletic events, especially at high school, middle school, and club level events. The sports physical therapist is looked upon to provide appropriate care in the event of an injury to or sudden illness of an athlete, or in the event of an unexpected medical emergency that arises in members of the coaching staff, officials, and fans.
Sports physical therapy, a diverse specialty practice, requires that certified specialists be able to examine, evaluate, develop a diagnosis and prognosis, and provide appropriate interventions for a wide variety of athletes. In addition to this part of the specialty practice, sports certified specialists must be able to provide emergency care. Frequently, the sports physical therapist (PT) is the “most medical” individual present at athletic events, especially at high school, middle school, and club level athletic events. The American Red Cross Emergency Responder training course affords the sports PT the opportunity to become trained in appropriate care of acute athletic injuries as well as illnesses that may be encountered. Additionally, this course is required by the Sports Specialty Council of the American Board of Physical Therapy Specialties (ABPTS) as one of the qualifications in order to sit for the ABPTS Board Certification examination for sports specialization. The course as offered by the Sports Physical Therapy Section (SPTS) is taught by Board Certified Sports Physical Therapists and is designed specifically for the sports PT. This course covers all aspects of emergency care that may be encountered by the PT working at athletic venues as well as emergencies that may occur in clinical settings or in the community. All aspects of emergency care including initial athlete evaluation, legal and ethical issues, CPR, airway insertion, open wounds, fracture/dislocation care, bandaging, splinting, management of the concussed athlete, management of suspected spinal cord injuries, and medical emergencies are addressed. This course has ample opportunity for practice of skills that will be needed by PT’s working on the sidelines/courtside at athletic events.

"On the Sidelines" will offer readers of the International Journal of Sports Physical Therapy suggestions and current evidence regarding topics related to emergent care of athletes. Subsequent columns will include topics of interest to the sports physical therapist working in athletic venues, regardless of the sport. Contributors will include Board Certified Sports Clinical Specialists with an interest in emergency care that will provide information that is useful in emergency situations.

With participation in sport comes the possibility of injury. (Figure 1, Figure 2) Many injuries are gradual and occur over time, while others are sudden and could be classified as emergencies. Emergencies range from musculoskeletal injury to medical conditions that arise during sport participation. Granted, not all emergencies are catastrophic, however, the sports physical therapist must be equipped with specific skills and specialized equipment in order to deal with any type of injury or emergency when it occurs. Basic sideline/courtside equipment for the sports physical therapist includes (but not limited to) equipment and tools that allow the sports physical therapist to deal with most emergencies that could occur during a sporting event or contest. (Table 1)

In addition to equipment and knowledge, the sports PT must also develop rapport with the coaching staff, school or club administration, team physician, and
local EMS personnel. Trust of the PT by the coaching staff (Figure 3) is an absolute must for a successful sports physical therapy program within an educational setting. Ground rules should be established between the sports physical therapist and the coaching staff especially related to return to play decisions and criteria. Should the sports physical therapist make the decision that a player is unable to return to competition, that decision should be honored by the members of the coaching staff. This relationship does not happen overnight. This is an ongoing process. When the coaching staff knows the sports physical therapist is making decisions based on what in the best interest of the players, this rapport will develop. The contrary is also true. When the sports physical therapist knows that the coach has the best interest of the players in mind during decision making regarding injury disposition, this will add to the relationship. Should the coaching staff override the decision of the sports physical therapist to hold a player from action and return the player to competition (against advice), the sports physical therapist may need to reconsider the decision to work with the team and the coaching staff. When the best interest of the player is not being considered, the liability of the sports PT increases considerably. This is especially important in the care of athletes under the age of 18 that would be encountered at the grade school, mid-

**Table 1. Sideline/Courtside Required Support Supplies**

Note: Supplies vary by type of sport being covered.

- Sideline/Courtside Emergency Kit (gloves, first aid supplies and tools [tweezers, scissors, etc.], taping/wrapping supplies)
- Splints, slings,
- Spine Board with straps and head immobilization device
- AED
- Oxygen Tank with regulator and oxygen administration device
- Set of airways
- Facemask removal tools
- Bag Valve Mask

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**Figure 2.** Basketball athletes involved in contact, a potential mechanism of injury.

**Figure 3.** Coach of High School football team. It is important to build rapport between the Sports physical therapist and the coaching staff.
dle school, and high school levels as well as club teams with players who are minors.

Caring for athletes at the time of injury and then seeing them through the rehabilitation process and return to play is one of the most rewarding aspects of sports physical therapy. (Figure 4) Rehabilitation starts at the time of injury. Prompt and accurate evaluation of the athlete’s injury, efficient management emergent conditions and injuries, and appropriate early referral of the athlete to other necessary medical providers will lead to decreased lost time due to injury. Proper early management allows the sports physical therapist to participate, as part of a multidisciplinary team, in returning the athlete to competition as quickly and as safely as possible. This should be the goal of every sports physical therapy program. When the coaches, administration, physician, parents, and fans buy into this program, the program will be successful.

REFERENCES