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ABSTRACT

Background: The lunge is a closed kinetic chain exercise that athletes frequently use as part of training and rehabilitative programs. While typically performed on a stable surface, modifications include the use of balance platforms to create an unstable surface and suspension equipment. Suspension training exercises are theorized to be higher demand exercises and may be considered a progression from exercises on stable surfaces. Comparison of muscle recruitment between the suspended lunge and the standard lunge has not been reported.

Hypothesis and purpose: The purpose was to compare differences in muscle recruitment between a standard lunge and a suspended lunge. We hypothesized that hip and thigh muscle recruitment with a suspended lunge would be greater than a standard lunge due to less inherent support with the suspended lunge exercise.

Study Design: Analytic, observational cross-sectional study design.

Methods: Thirty healthy participants (15 male and 15 female) voluntarily participated in this study. Electromyographic (EMG) muscle recruitment was measured in five hip and thigh muscles while performing a standard and suspended lunge. EMG was expressed as a percentage of EMG with a maximal voluntary isometric contraction (MVIC).

Results: Recruitment was significantly greater in the suspended lunge condition compared to the standard lunge for the hamstrings (p < .001), gluteus medius (p < .001), gluteus maximus (p < .001), and adductor longus (p < .001). There was no significant difference in rectus femoris recruitment between conditions (p = .154).

Conclusion: Based on EMG findings, the suspended lunge is a more demanding exercise for hip muscles, compared to the standard lunge.

Level of evidence: Level 3 Mechanism-based reasoning intervention study trial.

Clinical relevance: The results of this study can assist clinicians in designing and progressing lower extremity exercise programs. With greater muscle recruitment, the suspended lunge is a more demanding exercise for hip muscles and can be considered a progression of the standard lunge as part of an exercise program.

What is known about the subject? Muscle recruitment associated with the lunge exercise, variations of the lunge, and similar exercises has been reported. The use of suspension training exercise equipment has been reported for upper extremity exercises however not for the lower extremity.

What does this study add to existing knowledge? Results of this study provide novel EMG information related to the lunge exercise using suspension training exercise equipment. Clinicians can use this information designing lower extremity exercise programs.

Keywords: Electromyography, Exercise Therapy, Lunge, Suspension Training

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INTRODUCTION

The lunge is a closed kinetic chain functional multi-joint exercise that replicates movements found in sports and common daily activities. Clinicians use both closed kinetic chain and open kinetic chain exercises for lower extremity programs with closed kinetic chain exercises such as the lunge generally favored due to functional implications. Lower extremity exercises such as the lunge may be used with the goal of enhancing the performance of muscles surrounding the hip. Common lower extremity conditions that may benefit from enhancing hip muscle performance include, but not exclusive to patellofemoral pain, anterior cruciate ligament injury, and iliotibial band syndrome.

Based on electromyographic (EMG) levels of muscle recruitment, the standard lunge exercise has been shown to produce low to moderate EMG levels for hip and thigh musculature. EMG levels found with the standard lunge have been compared to modified lunge techniques as well as similar lower extremity exercises. Investigating the influence of trunk position on EMG activation with a standard lunge, Farrokhi et al. found that a forward trunk lean during the standard lunge exercise significantly increased gluteus maximus and biceps femoris EMG levels when compared to an upright trunk position. Recruitment of the vastus lateralis was not significantly different between the two conditions. Comparing the lunge to similar exercises, Boudreau et al. found the rectus femoris, gluteus maximus, and gluteus medius were recruited in a progression from least to greatest during a single-leg step-up-and-over-lunge, standard lunge, and single leg squat. Support provided by both extremities was hypothesized as a contributing factor to the step-up-and-over-lunge and standard lunge having lower EMG levels as compared to the single leg squat.

The use of suspension exercise equipment has become popular in the athletic community. Use of these devices decreases the stability component of an exercise which increases muscular demands while performing comparable exercises. For example, performing upper extremity exercises, such as the push-up, using suspension training equipment requires more muscle recruitment as compared to a standard push-up. To our knowledge, the use of suspension training equipment for lower extremity exercises is not reported. The purpose of this study was to investigate differences in muscle recruitment between a standard lunge and a suspended lunge exercise. We hypothesized that muscle recruitment in a suspended lunge would be greater than a standard lunge.

METHODS

Participants

Thirty healthy participants (15 male and 15 female) with a mean age of 23.9 ± 1.7 years volunteered to participate in this study (BMI: 24.21 ± 2.88). Participants were recruited via word of mouth. Based on an a priori power analysis, 24 or more participants were needed to detect differences in recruitment of 10% maximal voluntary isometric contraction (MVIC) or greater (effect size = 0.6) among the two testing positions, assuming correlations among repeated measures of .75 or greater, at 80% power and at alpha = .05. We recruited a sample size 25% greater than that indicated by the power analysis to offset potential attrition.

Inclusionary criteria included healthy individuals between the age of 18 and 30 years old with the ability to perform three consecutive repetitions of the two chosen exercises. Exclusionary criteria included any current pain, pathology, trauma, or lower extremity surgery that would compromise ability to perform the lunge exercises. Prior to beginning study procedures, all participants provided signed consent. The study was approved by the Institutional Review Board at the author's institution.

Instrumentation

A TRX® suspension trainer (San Francisco, CA) was used for the suspended lunge. The trainer was anchored to a support beam approximately eight feet above the floor.

Raw EMG signals were collected at 1000 Hz through a 16-bit NI-DAQ PCI-6220 AD card (National Instruments Corporation, Austin TX) with Bagnoli™ DE 3.1 double differential surface EMG sensors and a Bagnoli-16 amplifier (Delsys Inc., Boston, MA). The sensor contacts were made from 99.9% pure silver bars 10 mm in length and spaced 10 mm apart. The preamplifiers had a gain of 10 v/v. The combined preamplifier and main amplifier permitted a gain from 100 to 10,000 Hz. The common mode rejection ratio was 92 dB at 60 Hz, input impedance was greater than 1015 Ω at 100 Hz and estimated noise...
was less than 1.2 μV. Raw EMG signals were processed with EMGworks Data Acquisition and Analysis software (Delsys Inc., Boston, MA).

**Procedures**

This analytic, observational cross-sectional study was conducted in a research laboratory setting. Study procedures were explained to the participants upon arrival after which signed informed consent was provided. Participants rode on a stationary bike for five minutes as a warm-up. They were next screened to determine their ability to conduct three consecutive repetitions of a standard lunge. To determine leg dominance, participants were asked with which leg they would kick a ball. Electrodes were placed on the dominant limb rectus femoris, gluteus medius, gluteus maximus, hamstrings, and adductor longus as described by Crisweli. The rectus femoris electrode was placed on the anterior thigh half the distance between the anterior inferior iliac spine and proximal border of the patella. The gluteus medius electrode was along the proximal third of the distance between the most superior point of the iliac crest and the greater trochanter. The hamstring electrode was placed on the posterior thigh half the distance from gluteal fold to the popliteal fossa. The adductor longus was palpated during an isometric contraction and the electrode was placed directly over the muscle belly about 4 cm from the pubic tubercle. The skin where the electrodes were placed was scrubbed thoroughly with alcohol wipes to reduce surface impedance. All electrodes were placed in parallel with the muscle’s line of action.

Prior to performing the lunge exercises, EMG for the tested muscles was recorded during a “make test” in which the subject performed a maximal contraction over a period of five seconds. After instruction and a submaximal practice bout, a single MVIC was performed. Verbal encouragement was provided by examiners during each MVIC recording. For the gluteus maximus MVIC test, the subject was positioned prone on a treatment table with a pillow under their abdomen. The knee was flexed to 90°. A belt was looped around the table and the distal thigh with a towel placed between the belt and the thigh for comfort. The subject raised their thigh into the belt pushing their heel toward the ceiling. For the gluteus medius, the subject was positioned sidelying on the non-dominant side. The test leg was extended to neutral and supported with a small step stool in approximately 5° of hip abduction. A belt was wrapped under the table and over the superior surface of the test leg just proximal to the lateral malleolus. The subject performed the MVIC by raising their leg against the belt. To test the hamstring, the subject was positioned in prone with a pillow under the abdomen. The knee of the test leg was flexed to 90°. The examiner provided resistance at the subject's ankle as the subject attempted to flex the knee. The rectus femoris was tested in supine. The dominant leg was positioned in about 30° of hip flexion with the knee extended. The examiner provided resistance just proximal to the ankle as the subject attempted to raise the leg towards the ceiling. The adductor longus was tested with the subject positioned in side-lying on the dominant leg side. The non-dominant hip was flexed with the knee resting on a stool. The examiner provided a force proximal to the knee as the subject attempted to lift their leg.

The order of lunge exercise was randomized. Each lunge exercise was verbally explained and visually demonstrated. Illustrations of the exercises can be seen in Figure 1. The subject was allowed to practice prior to recording the lunge trial. The standard lunge was performed by positioning the foot of the dominant leg forward a distance equal to a measurement from the greater trochanter to the floor. Once positioned, the subject performed the lunge by flexing their forward knee to 90 degrees. The trunk was maintained in a vertical position. The subject’s hands were maintained on hips. The pace of descent and ascent were each three seconds in duration with a one to two second hold at the 90° knee flexion position. A metronome was used for pacing. The lunge depth and trunk position were monitored visually by the examiner. Three consecutive lunges were performed.

The suspended lunge was performed with the dorsum of the non-dominant foot placed in the suspension strap loop. The level of the TRX® suspension loop was adjusted and positioned to place the tibia parallel to the floor. The subject performed the lunge by sliding the suspended limb along with the torso in a posterior direction and flexing the forward knee to 90°. The pace of exercise, vertical trunk position and hand position was the same as during the standard lunge.
Data Processing
EMG signals were band-pass filtered between 20 and 450 Hz with a 4th order Butterworth filter and processed with a room mean square algorithm over 200-ms time constants with sliding windows. To standardize our EMG analysis, we identified from the rectus femoris EMG signal the descending and ascending phases of each lunge repetition. We subsequently analyzed data from the ascending phases only. During the ascending phase of each lunge repetition, we identified peak EMG recruitment from each muscle and analyzed the mean EMG signal over a one-second duration surrounding the peak. Our method for selecting EMG signals to analyze was similar to that of Farokhi et al, and enabled us to avoid analyzing low levels of EMG recruitment during lunge cycles that commonly occur at movement initiation and termination. Data for each participant were averaged across three lunge repetitions in both conditions.

STATISTICAL ANALYSIS
Descriptive statistics (mean and SD) for normalized EMG data were calculated and the distributions examined to assess whether data were normally distributed. Based on Shapiro-Wilk tests, data from eight of the 10 distributions departed significantly (p < .05) from being normally distributed. We therefore transformed the EMG data with natural logarithmic transformations and subsequently conducted our inferential statistical analyses with the transformed data. We next compared EMG data between the two lunge conditions with a repeated measures analysis of covariance (ANCOVA), using participant sex as a covariate in the analysis since others have reported sex differences in muscle recruitment in similar exercises. All inferential tests were conducted at α = .05. Data were analyzed using IBM SPSS Statistics 22.0 software (IBM Corp, Armonk, NY).

RESULTS
All participants that entered the study completed both exercise conditions. Significantly greater EMG muscle recruitment was found in the suspended lunge condition compared to the standard lunge for the hamstrings (p = .001), gluteus medius (p < .001), gluteus maximus (p < .001), and adductor longus (p < .001). No significant difference was found in rectus femoris EMG recruitment between conditions (p = .434). Data are presented in Table 1.

DISCUSSION
The purpose of this study was to compare magnitudes of muscle recruitment between the standard lunge and the suspended lunge. We hypothesized

Figure 1. Full knee flexion position for standard lunge (A) and suspended lunge (B).
that muscle recruitment in a suspended lunge would be greater than a standard lunge as a result of the unstable support for the trailing limb with the suspended lunge exercise. Our hypothesis was confirmed with four of the five muscles tested with the gluteus maximus, gluteus medius, hamstrings, and adductor longus demonstrating significantly greater muscle fiber recruitment. The rectus femoris did not have significantly greater muscle recruitment in the suspended lunge compared to the standard lunge. We hypothesize that the rectus femoris worked similarly in both exercises to control the motion at the hip and knee (of flexion and extension), whereas the other muscles were recruited in greater magnitude with the suspended lunge in order to stabilize the hip and pelvis in the frontal and transverse planes. Similar to our results, Farrokhi et al. did not find a difference in quadriceps recruitment with varied trunk positions during a squat exercise which may suggest quadriceps muscle recruitment is more related to body weight load than stability.

We expressed muscle recruitment as a percent of the MVIC. Digiovine et al. categorized EMG muscle recruitment greater than 60% MVIC as Very High, 41-60% MVIC as High, 21-40% MVIC as Moderate, and 0-20% MVIC as Low levels of recruitment. Based on these categories we found the rectus femoris muscle had a moderate level of muscle recruitment in both the standard and suspended lunge conditions. The gluteus medius moved from a low level of recruitment in the standard lunge to a moderate level of recruitment in the suspended lunge. The remaining muscles were in the low level of recruitment for both lunges however, all five muscles demonstrated statistically greater muscle recruitment (normalized to MVIC) in the suspended lunges as compared to standard lunges.

The low and moderate levels of muscle recruitment for the standard lunge have been reported previously. With a standard lunge, Boudreau et al. found the gluteus maximus and adductor muscle groups were in the moderate level of recruitment with the rectus femoris and gluteus medius groups in the low level of recruitment. Some of the difference in levels of activation as compared to our results may be explained by different methods utilized to establish the MVIC’s of the tested muscles. Whereas we tested muscles with the subject lying on a plinth, Boudreau tested participants in standing resulting in a different reference to determine the percent MVIC. Ekstrom et al. reported the gluteus maximus and gluteus medius to achieve the moderate level of recruitment with the hamstrings achieving only the low level of recruitment. The standard lunge was performed by stepping forward with the lead leg and holding a five-second isometric contraction with the lead leg knee flexed 90° then returning to the starting position. The timing of the descent and ascent phases were not described other than being performed slowly. Similar to our findings, Farrokhi et al. reported that the gluteus maximus and hamstrings achieved the low level of muscle recruitment for the standard lunge.

Muscle recruitment in the standard lunge has been compared to other single-leg closed kinetic chain exercises including the single-leg step up and single-leg squat. Boudreau et al. reported increasingly greater muscle recruitment for the gluteus maximus, gluteus medius, and rectus femoris starting with
The single-leg step up (16.5%, 15.2%, 10.8%, respectively), to the standard lunge (21.7%, 17.7%, 19.1%), and greatest recruitment being achieved with the single-leg squat (35.2%, 30.1%, 26.7%). Our results for recruitment during the standard lunge were similar for the same muscles. While muscle recruitment of the gluteus maximus, gluteus medius and rectus femoris for the suspended lunge in our study was less than the single-leg squat reported in the Boudreau et al. study, the suspended lunge may fit between the standard lunge and single-leg squat in the progression of lower extremity exercises, based upon magnitude of muscle recruitment (%MVIC).

Our study recruited healthy participants between the ages of 18 and 30 years, thus we are unable to report how lower extremity pathology or older and younger participants may affect muscle activation patterns. While it was determined that EMG muscle recruitment of the gluteus medius was greater in females, our purpose was to investigate the difference between lunge conditions, not between men and women. The study was under-powered to investigate this difference, risking a type 2 error for sex comparisons. Future studies should investigate if lower extremity pathology and/or sex differences influence muscle recruitment patterns when performing a lunge or suspended lunge.

CONCLUSIONS
Our results demonstrate that the suspended lunge is a more demanding exercise compared to the standard lunge, requiring greater muscle recruitment of the gluteus maximus, gluteus medius, hamstrings and adductor longus than with the standard lunge exercise. Therefore, the suspended lunge can be viewed as a progression from the standard lunge. Clinicians can use this information in designing exercise and physical therapy rehabilitation programs.

REFERENCES
ABSTRACT

**Background:** Return to activity decisions after anterior cruciate ligament reconstruction (ACL-R) are limited by functional performance tests often performed in a non-fatigued state. Fatigue can improve test sensitivity, but current methods to induce fatigue are typically bilateral tasks or focus on the quadriceps muscle in isolation.

**Hypothesis/Purpose:** To determine the effects of a two-minute lateral step-down fatigue test compared to a 30-second side-hop test on single-leg forward hop distance in healthy individuals. It was hypothesized that participants would demonstrate decreased hop distance with both tests, but the two-minute lateral step-down fatigue test would result in greater deficits in single-leg forward hop distance.

**Study Design:** Randomized crossover

**Methods:** Twenty healthy participants (16 females, 4 males; age = 23.7 ± 3.0 years, height = 153.8 ± 36.2 cm; mass = 64.4 ± 12.8 kg; Tegner = 6.8 ± 1.2) were asked to perform single-leg forward hop for distance pre- and post-fatigue. Participants were randomly assigned to one of the two fatigue tests, 30-second side-hop or 2-minute lateral step-down test, during the first visit. They returned within a week and performed the same sequence of tests but underwent whichever fatigue test was not assigned at the prior visit.

**Results:** There was a significant decrease (p < 0.001) in single-leg forward hop distance following the 30-second side-hop test (pre = 134.1 ± 23.7 cm, post = 126.2 ± 24.4 cm) and the two-minute lateral step-down test (pre = 135.0 ± 26.1 cm, post = 122.7 ± 27.4 cm). The decrease in hop distance was significantly greater (p < 0.001) for the two-minute lateral step-down test compared to the 30-second side-hop test.

**Conclusion:** The two-minute lateral step-down test resulted in a greater decrease in hop performance compared to the 30-second side-hop test. The results establish a threshold for expected changes that occur in a healthy population and that can then be compared with an injured athlete population. The two-minute lateral step-down exercise may be an effective method of inducing fatigue to better mimic performance in a sports environment to inform return-to-sport decisions.

**Level of Evidence:** Level 1b- Therapy

**Key Words:** Anterior cruciate ligament reconstruction, fatigue, knee, rehabilitation, return to sport
INTRODUCTION
The knee is the most commonly injured joint by adolescents, with about 2.5 million injuries per year in the United States.1 Estimates for anterior cruciate ligament (ACL) tears can range anywhere from 100,000 to up to 250,000 injuries per year; approximately 75% of those injuries result in ACL reconstruction (ACL-R).2 Decisions regarding return to activity following ACL-R are partially informed by a battery of functional performance tests, consisting of a range of jumping tasks and strength measurements.3,4 These functional performance tests typically include, but are not limited to, vertical jump, triple hop, and single-leg forward hop.5,6 The single-leg forward hop test is one of the most commonly used functional performance tests to measure the abilities of an individual in the later phases of rehabilitation post-injury.4,7 Despite wide use, the single-leg forward hop test has relatively poor psychometric properties (sensitivity=52%, specificity=97%, +LR=17.33, -LR=0.49), reducing the ability to identify abnormal symmetry (LSI <85%) between limbs after ACL injury.5

Fatigue may play a role in ACL injury risk, as rates tend to be higher toward the end of competition (e.g., second half, last quarter).8,9 A limitation of current functional performance test batteries is that they are often performed under non-fatigued conditions and may not be of sufficient demand to identify limb asymmetries.7 Although athletes following ACL-R are thought to be resistant to quadriceps fatigue in isometric conditions,10,11 they demonstrate deficits in explosive strength12 and endurance with dynamic contractions.13 While the role of fatigue is not fully understood, it has been shown to have mixed effects on coordination and motor control14 and single-leg forward hop distance.6 These mixed effects seen with the incorporation of fatigue may be due to lack of uniformity in fatigue protocols,14 which may not facilitate enough fatigue to produce the biomechanical changes associated with increased risk for non-contact ACL injuries. Fatigue protocols often involve both limbs at the same time (e.g., agility drills, repeated squats or jumping, running), limiting between-side comparisons. An alternative is to induce unilateral fatigue. In two previous studies, participants completed a single-leg extension task until failure at 50% or 80% of a one repetition maximum (1RM).6,15 This test has been shown to be reliable15 and results in decreased single-leg forward hop distance in both healthy15 and ACL-R populations.6 The addition of fatigue also improves the psychometric properties of the single-left forward hop test. Prior to fatigue, all individuals with a history of ACL-R demonstrated normal single-leg forward hop symmetry values (LSI ≥90%), but following fatigue, 68% of the participants demonstrated relevant impairments in hop symmetry (LSI <90%).6 This suggests that test sensitivity can be improved with the addition of a fatigue protocol. However, this approach has limitations: a leg extension machine may not be available in all clinical settings and the task only focuses on a single muscle, which is not reflective of sport demands. Although it is known that quadriceps muscle strength is an important outcome measure following ACL-R, it is not the only muscle group fatigued during physical activity; thus, a more global approach to fatigue may better simulate sports-related fatigue.

Several single-leg tasks have been used to provide insights into movement impairments following knee injury, including the side hop and lateral step-down.16,17 While these tests have not been used to specifically induce fatigue, both provide an anaerobic challenge and utilize minimal equipment. It is necessary to develop methods to effectively fatigue individuals in a manner that is more clinically pragmatic but still relevant (i.e., without the use of equipment), and can provide greater insight into rehabilitation progress and return-to-sport decision making. It is necessary to first determine whether either of these tests will impact single-leg hop performance, prior to introducing in a clinical population. Therefore, the purpose of this study was to determine the effects of a two-minute lateral step-down fatigue test compared to a 30-second side-hop test on single-leg forward hop distance in healthy individuals. It was hypothesized that participants would demonstrate decreased hop distance with both tests, but the two-minute lateral step-down fatigue test would result in greater deficits in single-leg forward hop distance due to the longer duration of the test and greater demands on lower extremity musculature.
METHODS
A randomized crossover design was used. Each participant performed one of two fatigue interventions, determined by a randomized table, during the first session and performed the other fatigue intervention during the second session, with three to seven days between testing sessions. The same investigator obtained measures during each session. The study was reviewed for ethical considerations and approved by the Institutional Review Board at Creighton University (IRB 959318). All participants completed an approved informed consent form, compliant with the Declaration of Helsinki, prior to study enrollment.

Twenty healthy participants (16 females, 4 males; age = 23.7 ± 3.0 years, height = 153.8 ± 36.2 cm; mass = 64.4 ± 12.8 kg; Tegner = 6.8 ± 1.2) volunteered for this study. Inclusion criteria included age 19-40 years, no history of knee surgery, and a Tegner Activity Scale score > 5 (heavy labor, competitive endurance sports, recreational sports- jogging on uneven ground at least twice weekly). Exclusion criteria included traumatic spine or lower extremity injury within the prior six months and inability to give consent or understand the experimental procedures. All participants completed a standardized health history form and the Tegner Activity Scale. Each session started with a five-minute warm up consisting of jogging on a treadmill at a self-selected speed and three single-leg vertical jumps with the dominant limb, defined as the preferred jumping limb (e.g., basketball layup), followed by the non-dominant limb. The single-leg vertical jump was performed as part of a separate reliability study.

The study protocol consisted of three parts: pre-fatigue evaluation, fatigue intervention, and post-fatigue evaluation. First, participants performed the single-leg hop for distance (Figure 1). They were instructed to hop as far forward as possible with a controlled single-limb landing, defined as maintaining position on a single leg for two to three seconds. A loss of balance or placing the contralateral limb on the ground to maintain support was determined to be a failed trial and the trial was repeated. The first trial was used as a warm-up and the maximum single-leg hop distance (cm) of trials two and three was used for data analysis. The dominant limb was tested prior to the non-dominant limb. Single-leg hop for distance has good within-session reliability (ICC = 0.98),15 good between-session reliability (ICC = 0.92 to .95),18,19 and an established minimal...
detectable change of 8.1% for the limb symmetry index\(^{19}\) and 13-14 cm for absolute single-leg hop distance.\(^{18}\)

Next, participants were randomized to either a 30-second side-hop (Figure 2A) test or two-minute lateral step-down test (Figure 2B). The 30-second side-hop test required participants to jump as many times as possible over two parallel strips of tape placed 40 cm apart on the floor.\(^{17}\) An unsuccessful jump was defined as touching the tape or the area inside the tape. The two-minute lateral step-down test required participants to perform a unilateral step-down from a 30.5 cm box (12-inches), tapping their heel to the floor each time, and completing this as many times as possible for two minutes. The number of step downs and side hops performed was recorded for descriptive purposes. Immediately following the fatiguing intervention, participants performed the single-leg hop for distance three more times, using the same protocol as the pre-fatigue measures. Following a three to five minute rest, participants repeated the same protocol (pre-fatigue, fatigue exercise, and post-fatigue) on the opposite limb. Participants returned three to seven days later and performed the same sequence of tests, but performed the fatigue test, which was not performed at the prior visit.

Sample size was based on a previous study\(^{15}\) utilizing an isolated quadriceps fatigue exercise to decrease single-leg forward hop distance (mean change = 10 cm, SD = 15) in healthy individuals. It was determined that at least 16 participants were necessary in order to detect a significant (\(\alpha = .05, 1-\beta = .80\)) change in single-leg forward hop distance following the fatigue protocol. The independent variables included the fatigue test (30-second side hop, two-minute lateral step-down), time (pre-test, post-test), and side (dominant, non-dominant). The dependent variable was single-leg forward hop distance (cm). Descriptive statistics, including frequency counts, were calculated for the outcome variables. A mixed model ANOVA was used to determine differences between sides and pre- and post-test measures for each fatigue test. A separate paired t-test was used to determine differences in hop test performance between tests using the average of the dominant and non-dominant limbs. Statistical significance was set \textit{a priori} at \(p \leq 0.05\). Effect sizes (Cohen’s \(d\)) were calculated for outcome variables using the mean difference between pre- and post-test trials and the pooled standard deviation. Effect sizes were interpreted as follows: small (0.20), moderate (0.50), and large (0.80).\(^{20}\)

\textbf{RESULTS}

There was not a significant interaction (side x time) for the 30-second side-hop test (\(p = 0.86\)) or the two-minute lateral step-down test (\(p = 0.33\)). The
compared to a 30-second side-hop test on single-leg forward hop distance in healthy individuals. The results confirmed our hypothesis that both fatigue tests would decrease single-leg forward hop performance, and that the two-minute lateral step-down test resulted in a significantly greater decrease in single-leg hop performance compared to the 30-second side-hop test. The two-minute lateral step-down test resulted in not only a greater average change from pre- to post-testing relative to the 30-second side-hop test (12.3 cm versus 8.0 cm), but also a larger effect size (-0.46 versus -0.33), allowing interpretation of the magnitude of this change. Thus, the current study provides evidence that single-leg forward hop distance is negatively impacted by the fatigue tests. Currently, return-to-sport protocols include functional hop tests, as well as objective quadriceps strength measures, in the clinical decision-making tree of returning athletes to sport after ACL-R. An LSI of >85-90% has been established as sufficient criteria to begin a return-to-sport progression.21 Limb dominance may impact LSI as the dominant limb demonstrated significantly greater (p< 0.05) single-leg forward hop distance compared to the non-dominant limb for both tests. Both fatigue tests significantly decreased (p <0.001) single-leg forward hop distance (Table 1), but the magnitude of this decrease was significantly greater (p <0.001) with the two-minute lateral step-down test compared to the 30-second side-hop test (Table 1). The frequency of observed changes in single-leg forward hop distance following fatiguing exercise is provided in Figure 3. Effect sizes were considered small to moderate for changes in single-leg forward hop distance following the 30-second side-hop test (d= -0.33) and the two-minute lateral step-down test (d= -0.46). The 30-second side-hop test resulted in decreased single-leg hop distance exceeding the 13 cm minimal detectable change in 15% of the trials, compared to 40% of the trials after the two-minute lateral step-down test.

**DISCUSSION**

The purpose of this study was to determine the effects of a two-minute lateral step-down fatigue test compared to a 30-second side-hop test on single-leg forward hop distance in healthy individuals. The results confirmed our hypothesis that both fatigue tests would decrease single-leg forward hop performance, and that the two-minute lateral step-down test resulted in a significantly greater decrease in single-leg hop performance compared to the 30-second side-hop test. The two-minute lateral step-down test resulted in not only a greater average change from pre- to post-testing relative to the 30-second side-hop test (12.3 cm versus 8.0 cm), but also a larger effect size (-0.46 versus -0.33), allowing interpretation of the magnitude of this change. Thus, the current study provides evidence that single-leg forward hop distance is negatively impacted by the fatigue tests.
accurate representation of the presence of asymmetry. Previous research demonstrated that, prior to fatigue, all individuals with a history of ACL-R demonstrated normal single-leg forward hop symmetry values (LSI >90%), but following fatigue, 68% of the participants demonstrated relevant impairments in hop symmetry (LSI <90%). This indicates that a non-fatigued single-leg forward hop LSI greater than 90% may not be a sufficient cut-off to allow athletes to return to sport. Adding a unilateral fatigue test may improve our ability to detect clinically meaningful differences between limbs for single-leg forward hop performance that may not be expressed in non-fatigued hop testing conditions.

There are two potential advantages of using the 30-second side-hop or the two-minute lateral step-down fatigue tests as opposed to previous fatigue protocols (i.e. leg extensor machine testing). The first is that there is strong potential of more effectively detecting strength and functional deficits post-ACL-R. A second benefit is that both fatigue tests may also provide insights into anaerobic performance differences between limbs or in comparison to healthy controls. The side-hop test has been utilized as an endurance task and used to differentiate between performance of the involved and uninvolved limb following ACL injury and reconstruction. As the quadriceps and other lower extremity muscles fatigue, this test can provide critical insights into what the knee can potentially withstand during sport. The lateral step-down test has been used clinically to examine performance as well as movement quality. The authors’ application of the lateral step-down test included two minutes per limb versus five repetitions or three minutes which have been used in previous studies. The decreases in single-leg forward hop distance after fatigue demonstrate potential for the fatigue test to decrease jumping performance. Although the number of repetitions performed for each of the tests was monitored, other measures were not captured to better quantify fatigue (e.g., rating of perceived exertion, electromyography). Previous studies have performed a unilateral leg-extension task at 50% or 80% of 1RM until failure to fatigue the quadriceps muscle. This resulted in a 17 cm decrease in hop performance for healthy individuals. Greater deficits following fatigue are seen in individuals with a history ACL-R on both the involved (30 cm) and uninvolved limb (25 cm). The minimal detectable change of the single-leg forward hop test is 13-14 cm, which indicates that changes less than 13-14 cm cannot be differentiated from measurement error and should be viewed with caution. While the 12 cm decrease in forward hop distance was close to the minimal detectable change, there is a compelling potential that when applied in a population with ACL-R, results would yield those that would

![Figure 4](image-url)
be comparable to that of the leg-extensor fatigue test (Figure 4) at 80% of a 1RM which resulted in approximately 17 cm decrease in forward hop distance.\textsuperscript{6,15} As seen in Figure 4, healthy participants (blue bars) had decreases in forward hop performance that were lower in magnitude compared to participants with a history of ACL reconstruction (red bars). Future studies should determine changes in single-leg forward hop distance following the fatigue protocols, outlined in the current study, for individuals with a history of ACL-R. The two-minute lateral step-down test and 30-second side-hop test offer a more pragmatic solution, as compared to current fatigue methods, to implementing fatigue testing in the clinic. Both require minimal time and equipment (30.5 cm step, stopwatch) and are relatively inexpensive compared to a leg-extension machine. Not only are these tests clinically useful, but also are more functional evaluative tests. During sporting activity quadriceps fatigue does not occur in isolation, but involves both central and peripheral mechanisms.\textsuperscript{32} It is also possible that avoidance patterns or compensatory strategies may be utilized to allow task completion and preserve quadriceps function. Individuals with a history of ACL reconstruction have been shown to rely more heavily on contributions from the hip and ankle to offset decreased contributions from the knee when performing a vertical jump\textsuperscript{33} or single-leg forward hop.\textsuperscript{34} Although the side-hop or lateral step down may be considered more functional-type tasks, compensatory strategies to preserve quadriceps function would not be available during a strictly knee extensor fatigue protocol. Future research should focus on the use of fatigue tests in athletes following ACL-R, as well as the use of 3-D motion capture and/or electromyographic (EMG) data to investigate the compensatory strategies individuals with a history of ACL-R use when fatigued.\textsuperscript{15,33,35} This information may better determine which type of fatigue protocol provides most relevant information to inform return to sport decisions.

A limitation of this study was that only young, healthy individuals were included, consisting of a greater number of female participants. It is known that females may demonstrate a different fatigue profile than males.\textsuperscript{36,37} Future studies should employ a more balanced recruitment of female and male participants and of sufficient sample size to allow between sex comparisons. A second limitation was that the order of limb testing was not randomized. Instead, the authors elected to test the dominant limb prior the non-dominant limb, a method used in previous studies.\textsuperscript{38,39} There is little consensus regarding an appropriate testing sequence for injured (involved then uninvolved; randomized) or healthy participants (right then left, dominant then non-dominant, randomized). A third limitation was that time-anchored tests (30 seconds, 2 minutes) were used that did not include a subjective or objective measure of fatigue such as rating of perceived exertion\textsuperscript{40,41} or changes in quadriceps EMG profile.\textsuperscript{37} It could be possible for a participant to not provide full effort during the fatigue test, which would then underestimate likely changes in single-leg forward hop performance.

The data provided by this study and future studies can give clinicians greater insight into the challenges associated with athletes post-ACL-R, as well as provide a more thorough return to pre-injury levels of performance in order to reduce the likelihood of re-injury and promote a safe and smooth return to sport.

**CONCLUSION**

Return-to-sport/activity decisions are informed by a battery of functional and strength tests that are typically performed in a non-fatigued state, which may inaccurately determine whether an athlete is fully ready to return to sport. Fatiguing exercise is thought to better identify asymmetries in single-limb forward hop performance, as demonstrated previously with a leg-extensor fatigue test. This results of the current study indicate that the two-minute lateral step-down test has the ability to significantly decrease hop performance in a healthy population, and that these decreases are comparable to changes observed in a healthy population with the leg-extensor fatigue test (Figure 4). Even more so, the two-minute lateral step-down test is a more pragmatic solution to testing athletes in a fatigued state as compared to a leg-extension machine. Both require minimal time and equipment (30.5 cm step, stopwatch) and are relatively inexpensive compared to a leg-extension machine. Not only are these tests clinically useful, but also are more functional evaluative tests. During sporting activity quadriceps fatigue does not occur in isolation, but involves both central and peripheral mechanisms.\textsuperscript{32} It is also possible that avoidance patterns or compensatory strategies may be utilized to allow task completion and preserve quadriceps function. Individuals with a history of ACL reconstruction have been shown to rely more heavily on contributions from the hip and ankle to offset decreased contributions from the knee when performing a vertical jump\textsuperscript{33} or single-leg forward hop.\textsuperscript{34} Although the side-hop or lateral step down may be considered more functional-type tasks, compensatory strategies to preserve quadriceps function would not be able available during a strictly knee extensor fatigue protocol. Future research should focus on the use of fatigue tests in athletes following ACL-R, as well as the use of 3-D motion capture and/or electromyographic (EMG) data to investigate the compensatory strategies individuals with a history of ACL-R use when fatigued.\textsuperscript{15,33,35} This information may better determine which type of fatigue protocol provides most relevant information to inform return to sport decisions.

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24. Schmitt LC, Paterno MV, Ford KR, Myer GD, Hewett TE. Strength asymmetry and landing mechanics at


ABSTRACT

Background: ACL injuries are common among sports populations and achieving adequate lower extremity strength is important prior to return to play. Access to isokinetic testing equipment that measures lower extremity strength is limited. Screening tools that measure functional criteria are accessible to clinicians, however the tools’ relationship to strength constructs have not been investigated in an ACL reconstructed (ACLR) population.

Purpose: The primary objective was to determine if relationships exist between isokinetic peak knee extension torque (PKET), peak knee flexion torque (PKFT), hamstring to quadriceps (HQ) ratios, and YBT-LQ performance following ACLR. The secondary objective was to observe differences in isokinetic strength ability between high and low performers on the YBT-LQ.

Study Design: Retrospective Chart Review

Methods: Medical records of forty-five ACL-reconstructed subjects, between five-12 months post-surgery were queried for functional assessment data collected during the institution’s standard outcome testing battery. Variables of interest included: demographic and anthropomorphic measures, YBT-LQ performance, and involved limb isokinetic PKET, PKFT, and HQ ratios. Performance on each measure, as well as asymmetry between sides, was analyzed using a correlation matrix.

Results: Statistically significant (p<0.01) relationships were identified between YBT-LQ anterior reach asymmetry and the PKET deficit (r=0.264). PKET and PKFT on the involved limb correlated to performance of anterior reach (r=0.391, p<0.01) (r=0.493, p<0.01), posteromedial reach (r=0.498, p<0.01) (r=0.577, p<0.01), and posterolateral reach (r=0.294, p<0.05) (r=0.445, p<0.01) respectively. Similar relationships existed on the uninvolved side, but to a lesser extent. High and low performers on the YBT-LQ demonstrated higher and lower extension torque deficits, respectively.

Conclusion: While each test measures unique constructs, there are associations between components of the tests. In the ACLR population, both the YBT-LQ and isokinetic strength testing can expose asymmetries and impact return to play decision making.

Level of evidence: 2b

Key words: ACL, Y-Balance test lower quarter, isokinetic testing, return to sports

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INTRODUCTION

ACL ruptures remain common among adolescents and young adults participating in sports resulting in about 150,000 to 200,000 ACL reconstructions performed each year.\(^1\) For an athlete to return to his or her selected sport or vigorous activity, ACL reconstruction surgery is often performed, followed by a rehabilitation program typically lasting six to 12 months.\(^1,2,3,4\) To date, there has been no consensus on criteria for return to sport nor have universal guidelines been established to determine readiness to return an athlete to previous level of sport, to decrease re-injury rates, or to preserve long-term joint health.\(^1,2,4,5\) In general, a combination of time after surgery, subjective report, graft laxity, joint range of motion, strength, and functional testing is commonly used to determine the athlete's physical readiness to return to prior level of activity.\(^1,2,6,7,8\)

With regard to assessing strength, one commonly reported criteria is the patient's ability to demonstrate isokinetic quadriceps strength of at least 85% of the non-injured lower extremity and a hamstring to quadriceps (HQ) ratio of 2:3.\(^6,10\) Researchers have historically promoted isokinetic testing as the best tool for quantifying torque asymmetries in lower limb strength.\(^11\) However, isokinetic dynamometers are expensive, require additional time and training, and are often inaccessible in a majority of clinical settings. To improve feasibility of quantifying deficits in lower limb strength and function, it may be beneficial to establish a screening tool that would capture strength deficits that are similar to those measured during isokinetic testing. An abundance of lower extremity screening tools have been reported in the literature, most of which incorporate some level of functional or sport specific criteria.\(^1,12\) Poor performance on certain tests has been associated with an elevated risk of lower extremity injury.\(^2,7,13\) The Y Balance Test for the Lower Quarter (YBT-LQ) (a derivative of the anterior, posteromedial, and posterolateral reaches of the Star Excursion Balance Test (SEBT)) is one such test with good to excellent intra-rater and interrater reliability that has been used to predict injuries in high school athletes.\(^14,15\) Dynamic balance tests, such as the SEBT and the YBT-LQ, have been shown to be a reliable measure of an athlete's functional abilities.\(^6,14,15,17\) Specifically, the YBT-LQ is able to capture differences between the injured and non-injured limbs. This may expose asymmetries at the limit of the athlete's stability (much like what may be observed during athletic movements), which can be of benefit when returning an athlete from an injury.

Since the YBT-LQ is a functional outcome measure that can be easily utilized in the clinic, it may serve as a good evaluative tool in determining return to sport. As such, it is important to understand how it correlates with other commonly reported measures such as quadriceps and hamstring strength. To date, there are few reports that have investigated the relationship between lower extremity muscular ability and YBT-LQ performance.\(^16,18,20\) These include EMG studies of lower extremity musculature during the Star Excursion Balance Test as well as one study comparing YBT-LQ performance with eccentric isokinetic knee flexion and extension torque in healthy subjects. The primary objective was to determine if relationships exist between isokinetic peak knee extension torque (PKET), peak knee flexion torque (PKFT), hamstring to quadriceps (HQ) ratios, and YBT-LQ performance following ACLR. The secondary objective was to observe differences in isokinetic strength ability between high and low performers on the YBT-LQ.

METHODS

Study Design

The study involved a retrospective analysis of patient data at an outpatient hospital-based sports medicine physical therapy clinic. The study was approved by the Duke University Health System Institutional Review Board.

Subjects

Males and females age 15-35 years with primary ACL reconstruction either in isolation or in combination with a meniscal repair or meniscectomy were included. Surgical procedures took place between 01/01/2007 – 10/15/2013 by one of three surgeons and included hamstring grafts, bone-patellar tendon-bone grafts, and allografts. Exclusion criteria included subjects who had undergone a revision procedure.

Procedures

The subject's medical record was queried for functional assessment data which was collected between...
five and 12 months post-operatively as part of the institution’s standard post-operative outcome testing battery. Demographic and anthropometric information was collected including: age, gender, laterality of injury, body mass index, surgical procedure and time after surgery. Key variables of interest for return to sport criteria included: isokinetic testing (concentric/concentric) performed at 60 degrees per second utilizing the Cybex Isokinetic Dynamometer (Humac®/Norm TM Testing and Rehabilitation System, Model 770 Computer Sports Medicine Inc, Medical Solutions Stoughton, MA) to obtain peak extensor and flexor torques, and HQ ratios. Isokinetic testing was administered by licensed physical therapists who underwent training for operating the testing equipment. YBF-LQ was performed utilizing the Y-Balance Test Kit™ (FunctionalMovement.com, Danville, VA) for maximum reach distance in the anterior, posteromedial, posterolateral directions. The composite score for each limb was calculated and normalized to limb length. YBF-LQ testing was administered by staff (physical therapists, athletic trainers, and biomechanics lab staff) who were certified through an online course and examination.

Isokinetic testing was conducted using the isokinetic dynamometer following the protocol outlined by Car done et al, as per the user manual.21,22 Concentric knee flexion and extension movements were assessed at the angular velocities of 60, 180 and 240 degrees per second. Tests were performed in sitting while ensuring stabilization by applying straps to the trunk, waist, and thigh. The inferior resistance pad was placed at a level one inch proximal to the medial malleolus and the superior pad was placed an inch below the malleolus. The lateral femoral condyle was used as an anatomic reference for the axis of rotation.22 The range of motion tested was 0-90 degrees. Five repetitions at 60 degrees per second, five repetitions at 180 degrees per second, and fifteen repetitions at 240 degrees per second were performed with a one minute rest interval between speeds. The patient was able to practice each speed for three repetitions prior to the test repetitions. Verbal motivation was provided during the test to encourage maximal effort. Torque values at the 60 degrees/second conditions were analyzed as this speed is most commonly reported in the literature.

Testing for the YBF-LQ followed a standardized protocol in which the subject started by standing with one foot on a stance plate with the most distal aspect of the foot at the starting line and then reached with the opposite leg in anterior, posteromedial and posterolateral directions.12 (Figure 1) A standard number of practice trials (up to six) were allowed in order to minimize a learning effect. Each direction was repeated three times and the best repetition for

![Figure 1. Y-Balance Test of the Lower Quarter.](image-url) The direction of reach is named relative to the stationary lower extremity: a. anterior reach, b. posteromedial reach, c. posterolateral reach.
each direction was recorded. The composite score, expressed as a percentage, was obtained by taking the average of the normalized reach scores ([anterior + posteromedial + posterolateral]/3*leg length).12

In all cases, isokinetic testing and YBT-LQ were considered standard of practice within the facility in which data were captured. The tests were performed during the same week, and not in the same order. All subjects followed standardized post-operative ACL rehabilitation guidelines staged by both chronological and biological healing time frames and graft type. The first phase focused on graft protection, normalization of gait pattern, early ROM, swelling management, initial quadriceps activation and kinetic chain strengthening. The second phase focused on establishing symmetrical knee ROM, achievement of active knee hyperextension, improved lower extremity strength, and good stability with dynamic knee activities. The third phase focused on improving strength to >85% of the non-involved extremity, performance of advanced proprioception exercises, improved aerobic endurance, initiation of plyometric exercises and return to running and functional training. The fourth phase focused on establishing equal bilateral lower extremity strength, balance, proprioception, and power in the lower extremities and return to sport activities.

**Sample Size**

Sample size was not determined prior to the retrospective review. Rather, all eligible patients within the defined timeframe in which this testing was standard of practice were targeted.

**Data Analysis**

For the primary purpose, analysis was performed using IBM SPSS version 23.0. Means and standard deviations were used to describe overall group descriptive statistics, as well as reported by male and female sex. All variables were analyzed for normality using a Shapiro Wilk test and 40% of variables did not exhibit a normal distribution. A correlation matrix was run using Spearman Rho correlation statistics, a nonparametric equivalent to the Pearson Product test. Values close to -1 or +1 suggested a strong association whereas value closer to 0 suggested no relationship. Relationships, as defined by Cohen, are 0.01-0.3 (weak), 0.3-0.5 (moderate), and 0.5-0.99 (strong).23 An alpha value of 0.05 was used to quantify statistical significance. To address the secondary purpose, the mean extensor and flexor peak torque values were calculated for the subjects who performed the anterior reach with an asymmetry of 1 or less (high performers) and an asymmetry of 4 or greater (low performers).

**RESULTS**

Data from the charts of 45 individuals who were seen from February 2011 to May 2014 was utilized. There were no more than seven days between the date of the isokinetic test and the date of the YBT-LQ test. Subjects were an average age of 21.1 ± 5.8 years and were primarily male (N=29, 22.6 ± 6.3 years). A total of 16 females (18.5 ± 3.6 years) were also included in the retrospective review. Demographics and anthropometrics for the subjects at the time of their surgery are detailed in Table 1. Correlations between isokinetic testing and YBT-LQ balance testing on the involved side (Table 2) and the uninvolved side (Table 3) are presented.

With regard to the YBT-LQ composite scores, the involved side was moderately correlated to the peak flexor torque production (r=0.362) (p<0.01). Peak flexor torque was also moderately correlated to both anterior (r=0.493), posteromedial (r=0.577), and posterolateral (r=0.445) reach distances on the involved side (p<0.01). On the uninvolved side, the relationship between peak flexor torque and reach distances were correlated, but, to a lesser extent (r=0.281-0.338). (Table 2) On the involved side, relationships also existed between peak extensor torque values and the anterior (r=0.591) (p<0.01), posteromedial (r=0.498) (p<0.01), and posterolateral (r=0.294) (p<0.05) reach distances. Again, relationships existed, to a lesser extent, between peak extensor torque and each reach distance on the uninvolved side, with only the posteromedial reach demonstrating a significant relationship (r=0.302) (p<0.05).

With regard to asymmetries between limbs, the most significant, though weak, relationship existed between the anterior reach asymmetry and the extensor torque deficit (r=0.264) (p<0.01). Also, the posteromedial reach asymmetry significantly was correlated to extension deficit (r=0.303) (p<0.05).
DISCUSSION

The primary purpose of this retrospective investigation was to determine whether relationships exist between isokinetic extensor and flexor peak torque values and YBT-LQ performance in a group of patients who had undergone ACLR. As functional testing batteries are often included in examination for return to sport, it is important to understand how different tests are related so that the measures included in such a battery minimize redundancy and demonstrate ideal validity and predictive value.

Additionally, YBT-LQ subjects were dichotomized into subgroups of low performers and high performers for additional observation. Those who demonstrated greater than a 4 cm side to side deficit on the YBT-LQ anterior reach (n = 14) were observed to show a side to side mean extensor deficit of 27.36 ± 19.12% on isokinetic testing compared to those that demonstrated less than or equal to 1 cm anterior reach deficits (n = 14) who had a mean extensor deficit of 12.43 ± 20.66%. However, there was only a minimal difference observed in side-to-side isokinetic flexor deficits (16.29 ± 20.40%; 17.07 ± 13.65%) for greater than 4cm or less than/equal to 1cm respectively.

Table 1. Descriptive values for male and female subjects.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Number</th>
<th>Height (m)</th>
<th>Weight (kg)</th>
<th>Age at Time of Surgery</th>
<th>Months after Surgery</th>
<th>Laterality of Involved Limb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>16</td>
<td>1.68±0.06</td>
<td>66.52±6.62</td>
<td>18.5 ± 3.6 yrs</td>
<td>8.2 ± 2.0 (5.5 – 12.0)</td>
<td>8 Left, 8 Right</td>
</tr>
<tr>
<td>Male</td>
<td>29</td>
<td>1.78±0.07</td>
<td>80.59±12.44</td>
<td>22.6 ± 6.3 yrs</td>
<td>7.2 ± 1.8 (5.5 – 12.0)</td>
<td>14 Left, 15 Right</td>
</tr>
<tr>
<td>Total</td>
<td>45</td>
<td>1.75±0.08</td>
<td>75.62±12.65</td>
<td>21.1 ± 5.8 yrs</td>
<td>7.6 ± 1.9 (4.7 – 12.0)</td>
<td>22 Left, 23 Right</td>
</tr>
</tbody>
</table>

Table 2. Correlation values (r) between Y-Balance Test variables and isokinetic variables with the involved limb, using Spearman Rho

<table>
<thead>
<tr>
<th>Isokinetic Measures</th>
<th>Anterior Reach Distance</th>
<th>Posterior-medial Reach Distance</th>
<th>Posterior-lateral Reach Distance</th>
<th>Asymmetry Anterior Reach</th>
<th>Asymmetry Posteromedial Reach</th>
<th>Asymmetry Posterolateral Reach</th>
<th>Composite Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extension Torque</td>
<td>.591**</td>
<td>.498**</td>
<td>.294*</td>
<td>.165</td>
<td>-.136</td>
<td>-.010</td>
<td>.268</td>
</tr>
<tr>
<td>Flexion Torque</td>
<td>.493**</td>
<td>.577**</td>
<td>.445**</td>
<td>.034</td>
<td>-.015</td>
<td>.032</td>
<td>.362**</td>
</tr>
<tr>
<td>Extension Deficit</td>
<td>-.144</td>
<td>-.135</td>
<td>.037</td>
<td>.264**</td>
<td>.303*</td>
<td>.117</td>
<td>-.162</td>
</tr>
<tr>
<td>Flexion Deficit</td>
<td>-.248</td>
<td>-.280*</td>
<td>-.186</td>
<td>.005</td>
<td>.063</td>
<td>-.152</td>
<td>-.139</td>
</tr>
<tr>
<td>HQ Ratio</td>
<td>-.037</td>
<td>.106</td>
<td>.216</td>
<td>-.075</td>
<td>.259</td>
<td>.054</td>
<td>.136</td>
</tr>
</tbody>
</table>

*=significant at p<0.05
**=significant at p<0.01
directions on the YBT-LQ and peak torques suggesting they measure similar constructs. This information is useful as it might allow one to use certain reach distances on the YBT-LQ to help make clinical judgments regarding the functional strength of the quadriceps and hamstrings. It also suggests that not all who perform poorly on the YBT-LQ will have poor torque output or that all who are weak, as measured using isokinetic testing, will fail the YBT-LQ. Those who do perform poorly on isokinetic testing and well on the YBT-LQ may have learned to adapt to strength deficits to better perform functionally. Conversely, those who perform well on isokinetic testing but poorly on functional testing may have other limitations that need to be addressed such as poor dorsiflexion range of motion or decreased balance and neuromuscular control.

Reach Asymmetries

It is important to understand what role asymmetries in both functional movement and isolated strength play in injury risk and readiness to return to sport. Plisky et al. found that an anterior reach difference of 4 cm or more or a composite score less than or equal to 94% of leg length for women on the SEBT during a pre-participation athletic screening was included in decision making for return to sport. The data presented in this study indicate that relations of varying degrees do exist between the two tests.

While limited studies examining the relationship between the YBT-LQ and isokinetic testing exist in a healthy population, Booysen et al compared eccentric knee extensor and flexor torque (as a measure of strength) to normalized YBT-LQ composite scores and found a significant relationship between knee extension torque and YBT-LQ scores in the non-dominant extremity of healthy soccer players. Their study did not include concentric strength measures and did not report relationships between strength and individual reach directions. In EMG studies performed on healthy, college-age subjects, vastus medialis contraction during the anterior and posteromedial directions of the star excursion balance test ranged from 66% to greater than 100% maximal voluntary isometric contraction (MVIC). This suggests a requirement for functional knee extensor strength during this task. Both YBT-LQ and isokinetic testing outcomes for the patients in the current study are similar to those reported in the literature. The results of the current study indicate that weak to moderate relationships exist between certain reach

| Table 3. Correlation values (r) between Y-Balance Test variables and isokinetic variables on Uninvolved limb using the Spearman Rho |
|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| Isokinetic Measures                             | Y-Balance Measures                              | Anterior Reach Distance | Posterior-medial Reach Distance | Posterior-lateral Reach Distance | Asymmetry Anterior Reach | Asymmetry Postero-medial Reach | Asymmetry Posterolateral Reach | Composite Scores |
| Extension Torque                                | .269                                            | .302*                   | .223                            | .157                            | .033                            | .132                            | -.026                            |
| Flexion Torque                                  | .293*                                           | .338*                   | .281*                           | .031                            | .010                            | .052                            | .161                             |
| Extension Deficit                               | -.026                                           | .068                    | .058                            | .264**                          | .303*                           | .117                            | -.044                            |
| Flexion Deficit                                 | -.236                                           | -.160                   | -.311                           | .005                            | .063                            | -.152                           | -.060                            |
| HQ Ratio                                        | .139                                            | .083                    | .146                            | -.079                           | -.013                           | .114                            | .326*                            |

*=significant at p<0.05
**=significant at p<0.01
a predictor of lower extremity injury.\textsuperscript{15} In a study examining risk factors for injuries in female soccer players, Soderman et al. found that of the five players who had sustained an ACL injury, all had a lower HQ ratio on the ACL-injured side than on their non-injured side.\textsuperscript{24} While the current study is retrospective in nature, and unable to provide predictive value regarding injury risk based on previously measured asymmetries, this data does demonstrate that asymmetries remain up to 12 months after ACL reconstruction. Secondary analysis examined a subset of athletes who demonstrated a meaningful clinical asymmetry identified by the current literature. Based on previous studies an asymmetry of more than 4 cm on the anterior reach component is considered “at risk” and for the purpose of this study served to define a low performer on YBT-LQ\textsuperscript{4,15}. Conversely, a high performer was defined as no greater than 1 cm anterior reach asymmetry. Subgroups of high and low performers allowed further investigation into how quadriceps or hamstring strength may impact performance on the YBT-LQ. Analysis of these subgroups revealed a greater deficit in knee extensor torque in those who were low YBT-LQ performers. High performers had a lower knee extensor torque deficit suggesting that quadriceps strength may influence performance on this component of the YBT-LQ. However, this is only present in the subgroups and not the group as a whole. Additional factors beyond quadriceps and hamstring strength contribute to performance on the YBT-LQ which, as intended by its creators, incorporates range of motion, closed chain stabilization, and balance in addition to strength.

**Limitations**

As with any study, limitations exist in the current report. First, because this investigation was conducted as a retrospective review, there are inherent limitations in the study design. For one, retrospective reviews can only study associations and not causality. Second, the investigators must rely on others, in this case multiple clinicians and researchers, for accuracy of conduct and reporting at the time of documentation. An additional limitation of this study is a small sample size with more males (29) than females (16). Thus, care should be taken when applying the study results to a larger heterogeneous population. Lastly, while the YBT-LQ is a derivative of the SEBT and the two are closely related, they are not interchangeable.\textsuperscript{25} Therefore, care must be taken when applying the results of this study to performance on the SEBT which may be more clinically affordable than the YBT-LQ. Similarly, alternative methods of strength testing, such as hand held dynamometry or one repetition maximum, should be compared with caution as these methods were not included in the current study.

**CONCLUSIONS**

Both the YBT-LQ and isokinetic testing may be administered independently to examine for performance and torque deficits in the ACL reconstructed population. Based on the relationships reported in this study, anterior reach asymmetry and extension torque deficit in ACL reconstructed knees are related. Individual reach distances and peak knee extension and flexion torques demonstrate stronger relationships in the involved knee versus the uninvolved knee. This suggests that, in ACL reconstructed patients, knee extensor and flexor strength is related to Y-Balance performance but cannot fully explain observed deficits. Neither test, in isolation can stand-alone and the combination of both functional and strength testing should be included in return to sport examination and assessment.

**REFERENCES**

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5. Petersen W, Zantop T. Return to play following ACL reconstruction: survey among experienced...


20. HU
ABSTRACT

Background: Patellofemoral pain is common in physically active adults. Females with patellofemoral pain have been shown to have posterolateral hip muscle weakness, but there is a paucity of research examining hip muscle strength in males with patellofemoral pain.

Hypothesis/Purpose: The purpose of this study was to examine posterolateral hip muscle strength in males with patellofemoral pain compared to asymptomatic males. It was hypothesized that males with patellofemoral pain would have decreased strength of the hip extensor, hip external rotator, and hip abductor muscles compared to healthy, asymptomatic males.

Study Design: Descriptive, cross-sectional

Methods: Thirty-six adult males with patellofemoral pain and 36 pain-free males participated in the study. The patellofemoral pain group were required to have retropatellar pain reproduced by activities that loaded the patellofemoral joint (squatting, descending stairs, etc.). Peak isometric torque of the hip extensors, hip external rotators, and hip abductors was measured with an instrumented dynamometer. Torque was normalized by body mass and height. Between-group differences were analyzed with parametric or non-parametric tests, as appropriate. The level of significance was adjusted for multiple comparisons.

Results: Hip extensor torque was significantly reduced in the patellofemoral pain group compared to the control group ($p = .0165$). No differences were found between groups for the hip external rotators or hip abductors ($p > .0167$).

Conclusion: Males with patellofemoral pain appear to have weakness of the hip extensors, but unlike females with patellofemoral pain, they do not appear to have weakness of the hip abductors or hip external rotators. The findings of this study suggest that muscle strength factors associated with patellofemoral pain in males may be different from muscle strength factors in females. Clinicians examining and designing plans of care for male patients with patellofemoral pain should consider that the hip abductors and hip external rotators may not be weak in men with this condition.

Level of evidence: Level 3

Key words: Anterior knee pain, hip muscles, male, patellofemoral joint, strength testing
Although there is strong evidence for hip muscle weakness as a factor associated with PFP in females, there is conflicting evidence concerning hip muscle strength in males with PFP. A systematic review examining hip muscle weakness in PFP in both genders reported there was only limited evidence that males with PFP had reduced isometric hip abductor strength, reduced eccentric isokinetic hip external rotator strength, and no difference in eccentric isokinetic hip abductor strength compared to control males. Additional studies including both males and females with PFP reported less hip abductor isometric strength and less eccentric hip abductor torque, but no significant difference in hip abductor torque between males with PFP and control males. Mixed-gender studies examining hip external rotator strength have also had conflicting results, with reports of no significant difference between males with PFP and controls for hip external rotator isometric strength while another study reported that males with PFP had reduced concentric and eccentric hip external rotator torque. More recently, Bolgla et al. performed a secondary data analysis of baseline data from male participants of a mixed-gender randomized clinical trial (RCT) and found no differences in peak isometric force between males with PFP and control males. However, in another secondary data analysis of the same RCT, PFP male responders to hip muscle strengthening were found to have increased hip extensor, hip external rotator, and hip abductor isometric force following the intervention. The authors concluded that some males may have weakness of hip musculature, given the positive response to hip muscle strengthening. In view of the limited and conflicting evidence regarding hip muscle strength in males with PFP, additional studies of hip muscle strength in males with PFP are needed.

The purpose of this study was to examine posterolateral hip muscle strength in males with PFP compared to asymptomatic males, specifically those muscles reported in a systematic review to be weak in females with PFP. We hypothesized that males with PFP would have significantly lower peak isometric muscle torque of the hip abductors, hip...
external rotators, and hip extensors compared to males without PFP.

METHODS
A descriptive cross-sectional study design was used to examine peak isometric hip muscle torque in two groups of males aged 18–45 years: males with PFP and an asymptomatic male control group. Testing took place in a research laboratory at the University of the Sciences in Philadelphia, Pennsylvania. Study investigators were physical therapists and student physical therapists trained by the lead investigator. The study was approved by the University of the Sciences Institutional Review Board.

Participants
Participants were recruited from the University of the Sciences and the local community via advertisement by flyers, meetings with university athletic teams, referral from local physical therapists, and word of mouth. The inclusion and exclusion criteria were consistent with previous studies. Inclusion criteria for both groups were (1) age 18–45 years; (2) male gender. Additional inclusion criteria for the PFP group were: (1) history of unilateral or bilateral retropatellar pain for ≥ 1 month; (2) the presence of pain with ≥ 3 of the following: prolonged sitting, stair ascent or descent, ascending or descending inclines, running, squatting, kneeling, hopping, jumping, and palpation of the patellar facets or borders. Exclusion criteria for the PFP group were: (1) other musculoskeletal knee or hip conditions that may cause pain or weakness including patellar tendonitis, ligament tears, iliotibial band syndrome, Osgood-Schlatter syndrome, a history of hip or knee joint surgery, hip or knee fracture within the previous two years, acetabular labrum tear; (2) neurological or systemic conditions that may cause weakness or pain such as multiple sclerosis, cerebral palsy, and rheumatoid arthritis. An additional control group inclusion criterion was: no knee pain at time of enrollment or that caused activity limitation for > 2 days in the previous year. Control group exclusion criteria were: (1) all PFP group exclusion criteria; (2) the presence of pain with ≥ 3 of the provocative activities listed as inclusion criteria for the PFP group.

Potential participants were screened for study appropriateness with a questionnaire. Those who initially met all inclusion and exclusion criteria for one of the groups were invited to participate. Written informed consent was obtained and participants’ rights were protected during the study.

An a priori sample size calculation was performed for each muscle group using study results for hip muscle isometric force in females with PFP using G*Power 3.1.6 statistical software. Required sample size to be sufficiently powered was 20, 48, and 72 participants for the hip external rotators, hip extensors, and hip abductors, respectively (α = .05, power = .80, effect size 1.37, 0.83, and 0.67 [hip external rotators, hip extensors, and hip abductors, respectively]). A sample of 72 participants was planned, based upon the hip abductor muscle test.

Self-reported Symptom Severity, Function, and Activity
Participants completed questionnaires including demographic data, relevant past medical history, medications, and quantification of pain related to the involved knee using an 11-point numeric pain rating scale (NPRS) where 0 = no pain and 10 = worst pain. The NPRS is a reliable and valid measure of pain intensity that is responsive to change in persons with PFP. Participants completed the Lower Extremity Functional Scale (LEFS), a self-report questionnaire of function for persons with LE conditions that is reliable and responsive to change in persons with PFP. The LEFS is scored from 0-80, with 80 = full function. Participants also completed the Tegner Activity Scale, a self-report questionnaire of activity level reported to be valid, reliable, and responsive to change for persons with knee injuries. The Tegner Activity Scale is scored from 0–10, with 10 being most active.

Isometric Muscle Torque Testing
Peak isometric muscle torque of the hip abductors, hip extensors, and hip external rotators was measured with a Primus RS™ instrumented dynamometer (BTE Technologies, Inc., Hanover, Maryland, USA). The painful LE of PFP group participants was tested, or the most painful LE in cases of bilateral PFP. The matched side, right or left, of control group participants was examined. Muscle testing order was randomized with a random number generator. Lever arm length from the dynamometer was recorded for muscle force calculation from peak torque data.
The dynamometer lever arm was locked in place to prevent motion during all tests. Participant test positions for each muscle group were consistent with positions used in previous studies.20,38,47,49,50 The hip external rotator test was performed with participants seated with the hips and knees at 90° flexion (Figure 1).38,49,50 The dynamometer resistance pad was positioned with the distal edge just proximal to the medial malleolus. Participants were stabilized with straps around the trunk and over each thigh to maintain hip and trunk positions during testing.49,50 The hip extensor test was performed with the participants lying prone with both hips in neutral anatomical position (Figure 2).20,47,50 In an attempt to isolate the gluteus maximus muscle, the knee of the tested LE was flexed to 90° and one investigator monitored maintenance of this position to avoid compensatory LE motion.51 Straps were used around the trunk and untested LE to maintain neutral trunk and hip position during testing. The resistance pad was positioned against the posterior thigh just proximal to the popliteal fossa. The hip abductor test was performed with the participants in sidelying, tested LE uppermost, with the hip and knee in neutral anatomical position (Figure 3).20,47,50 The untested LE was placed in approximately 45° hip and knee flexion. Pillows were placed between participants’ LE to maintain proper tested LE position. A strap around the trunk was used to maintain neutral trunk position during testing. The resistance pad was placed...
participants were tested with the same study procedures on two sessions three to seven days apart. Muscle group testing order was matched between sessions. Intraclass correlation coefficients (2,k) (ICC_{2,k}) were used to evaluate reliability and standard error of measurements (SEM) were used to evaluate measurement precision. Results indicated excellent test-retest reliability for all torques as all ICC_{2,k} values were > 0.7555 (Table 1).

Statistical Analysis
Statistical analysis was conducted with SPSS statistical software, version 24 (IBM Corp., Armonk, New York, USA). Descriptive statistics included means and standard deviations (SD); medians and interquartile ranges were calculated for non-normally distributed data. Data were tested for normality with Shapiro-Wilk tests. Group comparisons for normally distributed variables were examined with independent t-tests, 1-tailed, \( p < .05 \). Non-normally distributed data were analyzed with Mann-Whitney U tests, 1-tailed, \( p < .05 \). The level of significance was adjusted with a Bonferroni correction for multiple comparisons, with resultant significance level of \( p < .0167 \). Cohen’s \( d \) effect sizes were calculated using G*Power 3.1.6 statistical software. Effect sizes were interpreted as small (0.20), medium (0.50), and large (0.80).
The PFP group exerted significantly less isometric hip extensor torque compared to the control group. No significant differences between groups were found for isometric torques of the hip abductors and hip external rotators (Table 3). A medium effect size for differences between groups for hip extensor torque was present (Cohen’s $d = 0.514$). Effect

### RESULTS

Seventy-two males participated in the study, 36 in each group. No differences were present between groups for height, mass, body mass index, or physical activity level. The PFP group was slightly older than the control group, had more pain on the NPRS, and had lower function on the LEFS (Table 2).

<table>
<thead>
<tr>
<th>Muscle Group</th>
<th>Left Lower Extremity</th>
<th>Right Lower Extremity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICC2,k*</td>
<td>SEM†</td>
</tr>
<tr>
<td>Hip abductors</td>
<td>0.963</td>
<td>0.053</td>
</tr>
<tr>
<td>Hip extensors</td>
<td>0.987</td>
<td>0.030</td>
</tr>
<tr>
<td>Hip external rotators</td>
<td>0.894</td>
<td>0.033</td>
</tr>
</tbody>
</table>

Abbreviations: ICC= intraclass correlation coefficient; SEM= standard error of measurement
*Intraclass correlation coefficient (2,k)
†Standard error of measurement, expressed in Newton-meters of torque.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Patellofemoral Pain Group*</th>
<th>Control Group*</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, median (IQR), y</td>
<td>23.5 (6)</td>
<td>22.0 (5)</td>
<td>.035†</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.79 (0.08) [1.76, 1.81]</td>
<td>1.77 (.09) [1.74, 1.80]</td>
<td>.323‡</td>
</tr>
<tr>
<td>Weight, median (IQR), kg</td>
<td>79.60 (22.70)</td>
<td>83.53 (20.91)</td>
<td>.656⁠</td>
</tr>
<tr>
<td>Body mass index, median (IQR)</td>
<td>24.88 (3.85)</td>
<td>26.34 (4.15)</td>
<td>.374†</td>
</tr>
<tr>
<td>Lower extremity dominance, right / left, No.</td>
<td>33 / 3</td>
<td>32 / 4</td>
<td>NA</td>
</tr>
<tr>
<td>Painful lower extremity, unilateral / bilateral, No.</td>
<td>20 / 16</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Tested lower extremity, right / left, No.</td>
<td>20 / 16</td>
<td>20 / 16</td>
<td>NA</td>
</tr>
<tr>
<td>Numeric pain rating scale score§</td>
<td>4.17 (1.92) [3.52, 4.82]</td>
<td>0 (0) [0, 0]</td>
<td>&lt;.001⁠</td>
</tr>
<tr>
<td>Lower Extremity Functional Scale score, median (IQR)**</td>
<td>71 (11)</td>
<td>80 (0)</td>
<td>&lt;.001†</td>
</tr>
<tr>
<td>Tegner Activity Scale score, median (IQR)††</td>
<td>5.5 (2)</td>
<td>7.0 (2)</td>
<td>.060⁠</td>
</tr>
</tbody>
</table>

Abbreviations: IQR= interquartile range; No= number; NA= not applicable
*Values are expressed as mean (SD) [95% confidence interval] unless otherwise indicated.
†Mann-Whitney $U$ test, 2-tailed
‡Independent $t$ test, 2-tailed
§The range for possible scores is 0 to 10, with 10 the worst pain.
**The range for possible scores is 0 to 80, with 80 the best function.
††The range for possible scores is 0 to 10, with 10 the highest activity level.
The purpose of this study was to determine if males with PFP have weakness of the posterolateral hip muscles. The authors hypothesized that males with PFP would have reduced isometric peak torque of the hip abductors, hip extensors, and hip external rotators compared to asymptomatic control males. The findings partially supported the hypotheses. The PFP group had significantly lower peak isometric hip abductor torque and hip external rotator torque were small (Cohen’s $d = 0.211$ and $0.413$, respectively). Post hoc analysis of isometric muscle force expressed as a percentage of body mass had similar results: the PFP group had significantly lower isometric hip extensor force compared to the control group and no differences between groups were present for hip abductor or hip external rotator isometric force (Table 3).

**DISCUSSION**

The purpose of this study was to determine if males with PFP have weakness of the posterolateral hip muscles. The authors hypothesized that males with PFP would have reduced isometric peak torque of the hip abductors, hip extensors, and hip external rotators compared to asymptomatic control males. The findings partially supported the hypotheses. The PFP group had significantly lower peak isometric hip abductor torque and hip external rotator torque were small (Cohen’s $d = 0.211$ and $0.413$, respectively). Post hoc analysis of isometric muscle force expressed as a percentage of body mass had similar results: the PFP group had significantly lower isometric hip extensor force compared to the control group and no differences between groups were present for hip abductor or hip external rotator isometric force (Table 3).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Patellofemoral Pain Group*</th>
<th>Control Group*</th>
<th>Mean Difference</th>
<th>95% CI of the Difference</th>
<th>$p$-Value†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abductors</td>
<td>.658 (.233)</td>
<td>.703 (.190)</td>
<td>.045</td>
<td>[-.055, .145]</td>
<td>.1860</td>
</tr>
<tr>
<td></td>
<td>[.579, .736]</td>
<td>[.638, .767]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External rotators</td>
<td>.350 (.118)</td>
<td>.396 (.100)</td>
<td>.045</td>
<td>[-.006, .097]</td>
<td>.0420</td>
</tr>
<tr>
<td></td>
<td>[.310, .390]</td>
<td>[.362, .429]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extensors</td>
<td>.411 (.181)</td>
<td>.512 (.210)</td>
<td>.101</td>
<td>[.009, .193]</td>
<td>.0165‡</td>
</tr>
<tr>
<td></td>
<td>[.350, .472]</td>
<td>[.441, .583]</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 3. Group averages for hip muscle torque (body mass and height-normalized) and hip muscle force (percent body weight)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Patellofemoral Pain Group*</th>
<th>Control Group*</th>
<th>Mean Difference</th>
<th>95% CI of the Difference</th>
<th>$p$-Value†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip muscle torque‡</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abductors</td>
<td>35.91 (12.92)</td>
<td>38.98 (10.87)</td>
<td>3.07</td>
<td>[-2.55, 8.68]</td>
<td>.1395</td>
</tr>
<tr>
<td></td>
<td>[31.54, 40.29]</td>
<td>[35.31, 42.66]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External rotators</td>
<td>18.61 (6.35)</td>
<td>21.16 (5.19)</td>
<td>2.55</td>
<td>[-0.18, 5.27]</td>
<td>.0335</td>
</tr>
<tr>
<td></td>
<td>[16.46, 20.76]</td>
<td>[19.40, 22.91]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extensors</td>
<td>22.87 (10.10)</td>
<td>28.44 (11.40)</td>
<td>5.57</td>
<td>[0.51, 10.63]</td>
<td>.0160§</td>
</tr>
<tr>
<td></td>
<td>[19.45, 26.28]</td>
<td>[24.58, 32.30]</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: CI= confidence interval; % BW= percentage of body weight; SD= standard deviation

*Values are expressed as mean (SD) [95% confidence interval].
†Independent $t$ test, 1-tailed.
‡Values are Newton-meters of torque/(mass in kilograms)(height in meters).
§Significant difference, $p < .0167$.
**Values are kilograms of force/mass in kilograms.
extensor torque compared to controls, with a medium effect size (Cohen's $d = 0.514$). No differences were found between groups for hip external rotator and hip abductor peak isometric torques. In addition, the PFP group had significantly greater pain and significantly lower function compared to the control group.

The finding of reduced hip extensor muscle group torque in males with PFP is consistent with systematic reviews of PFP in females, which report strong evidence for weakness of hip extensors associated with PFP. But the current findings differ from those of Bolgla et al. who did not find significant differences between males with PFP and control males for any hip muscle. The results of the post hoc analysis, a calculation of the force as a percentage of body weight (%BW), enabled us to compare the current study results more directly with earlier studies. Using data from the prior study, the participants' results were lower for hip extensor %BW (Bolgla et al., PFP = 28.5, control = 31.3). Both studies examining hip muscle strength in males with PFP tested the hip extensors with the knee flexed to 90°, resulting in primarily gluteus maximus recruitment. The different findings may be due to varied examination methods of peak isometric muscle force/torque: Bolgla, et al. used a handheld dynamometer (HHD) held against participants by straps anchored to objects while the current study used an instrumented dynamometer. Although research studies have demonstrated that HHD attached to a metal anchoring system is reliable for strength testing of the hip abductors and hip flexors, hip extensor strength test results were found to be less reliable. One problem that has been reported during LE strength testing with HHD is “off center” loading of the dynamometer load cell, which may cause inconsistent results. Off center loading may have occurred in the present study as well as in the study by Bolgla, et al. and may be one cause of differing results.

Different exercise participation levels and different pain intensity for participants between studies also may have caused differing results for the hip extensors. Intense levels of physical activity were reported to be associated with greater pain compared to moderate physical activity levels in women with PFP. Hip abductor and hip external rotator strength were not associated with function or pain in persons with PFP; however, no examination of hip extensor strength and function was reported. Inclusion criteria for the study by Bolgla, et al. required males to exercise for a minimum of 30 minutes per day, at least three days per week for the six months immediately prior to study enrollment. In the current study, inclusion criteria did not require a minimum exercise frequency (participants reported a variety of physical activity levels) and there was no minimum pain intensity rating. The greater hip extensor force %BW in the study by Bolgla, et al. compared to the present study may have been due to increased physical activity/exercise frequency by subjects in the earlier study. The study by Bolgla, et al. set a minimum pain intensity rating of 3 cm on a 10 cm visual analog scale (10 cm = worst pain). Increased knee pain in persons with PFP was shown to result in an acute reduction in hip extensor isometric strength. It is unlikely that the differing results between the present study and the study by Bolgla, et al. were due to differences in pain intensity, since the mean (SD) NPRS for the PFP group in our study was 4.17 (1.92), similar to 4 cm on a 10 cm visual analog scale. Thus, participants in the current study as well as the study by Bolgla, et al. appear to have had similar knee pain intensity levels. Although the impact of physical activity on PFP is still unclear, differing physical activity levels may have been responsible for different pain intensity and different study results. The current study findings demonstrate that some males with PFP may have associated hip extensor muscle weakness whereas the prior study's findings indicate that in males who exercise at a high frequency, factors other than hip muscle weakness may be involved.

Contrary to the authors' hypothesis, hip abductor and hip external rotator torque were not found to be different between groups. This is different from systematic reviews in females with PFP, which reported strong evidence for weakness of the hip abductors and hip external rotators associated with PFP. Our finding of no hip abductor weakness is also different from the findings of the systematic review by Rathleff, et al. However, the current findings are consistent with those of prior studies examining males with PFP. This study adds to findings of earlier studies that hip abductor weakness and hip external rotator weakness do not appear to be associated with PFP in males. This may indicate that weakness of the hip
abductors and hip external rotators are not factors associated with PFP in males, as they are in females.

The findings from the current study add to reports of gluteus maximus weakness in PFP as significantly lower hip extensor torque was found for the PFP group. The testing position for the hip extensors used in this study is reported to primarily recruit the gluteus maximus. Gluteus maximus weakness may result in excessive hip internal rotation motion and medial collapse of the knee. It may be that weakness of the gluteus maximus is the primary hip muscle requiring strengthening in males with PFP. This is consistent with Bolgla et al.’s findings that male PFP responders to hip muscle strengthening improved most in hip extensor and hip external rotator force and only minimally in hip abductor force. Since hip abductor weakness does not appear to be present in males with PFP, strengthening the hip abductors for males with PFP may not be as critical as it is for females with PFP. Additional research is needed to determine if males with PFP have reduced hip muscle endurance or altered gluteal muscle activation.

This study had some limitations. The PFP group was significantly older than the control group (23.5 [6] y versus 22.0 [5] y, respectively). However, the groups were similar with respect to height, weight, body mass index, and physical activity level. To combine results, torque data was normalized by height and weight, which we believe should minimize differences due to age. The authors did not control for physical activity level or a minimum level of pain as was done in prior studies. While this may seem a limitation, there was no significant difference due to physical activity between our groups. Therefore, the current study findings may be more generalizable than prior studies, since they apply to males of all physical activity levels. Finally, the power analysis was based on data from females, so the sample size may not have been adequate for males.

**CONCLUSION**

The results of this study suggest that males with PFP may have hip extensor muscle weakness, specifically weakness of the gluteus maximus muscle. Males with PFP do not appear to have weakness of the hip abductors or hip external rotators. These findings suggest that males with PFP may have different hip muscle impairments than females with PFP.

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ABSTRACT

Background: Hip–spine incoordination can cause low back pain (LBP) in adolescents. Hip–spine coordination, including the lumbopelvic rhythm (LPR) and the lumbar–hip ratio (LHR), can be used to assess lower limb and spine function. However, there are no reports of the values of LPR or LHR in adolescent soccer players with and without LBP.

Purpose: The purpose of this study was to clarify the effect of LBP on LPR and LHR during trunk extension among adolescent soccer players.

Study Design: A cross-sectional observational study.

Methods: One hundred and nine adolescent soccer players were recruited and divided into two groups, one with and one without LBP. Using three-dimensional motion analysis, participants range of motion (ROM) of the lumbar spine (LS) and hip during trunk and hip extension was measured to calculate the LPR and LHR. Paired, two-tailed t-tests were used to compare the LS and hip ROM between the non-LBP and LBP groups, two-way repeated measures analysis of variance was used to compare time with the non-LBP and LBP groups for LHR, and linear prediction was used to describe the LPR.

Results: The maximum LS ROM in the LBP group was significantly less than that in the non-LBP group by 6.6° (p = .005). There was no difference in the maximum hip ROM between the groups (p = .376). The LHR did not change during trunk extension (F [4, 428] = 1.840, p = .120), the mean LHR was 4.6 in the non-LBP group and 3.7 in the LBP group, and there was no difference between the groups (p = .320). The linear function of the LPR indicated, that when the hip joint was extended by 1°, the LS extended by 3.2° in the non-LBP group ($R^2 = .997, p < .001$) and 2.8° in the LBP group ($R^2 = .999, p < .001$).

Conclusion: LBP inhibited lumbar motion relative to hip extension as LPR was smaller in the LBP group than in the non-LBP group. However, there was no difference between the groups in LHR because inter-individual variability affected the LHR.

Level of Evidence: 3b

Keywords: Adolescent; low back pain; lumbar–hip ratio; lumbopelvic rhythm; trunk extension

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INTRODUCTION
There have been some reports on adolescent lumbar disorders.1-6 Low back pain (LBP) is the seventh most common disorder and sports injury,1 and the fourth most common soccer-related disorder.6 The odds ratio for soccer-related LBP ranges between 1.6 and 1.7.2,3 Factors related to LBP during adolescence include disk degeneration4 and spondylolysis,5 with the pathomechanics of disk degeneration relating more to trunk flexion than trunk extension.7,8 However, trunk extension also relates to intervertebral disk disorders. Jinkins et al.8 measured disk degeneration using MRI during trunk extension in the upright position and reported the relationship between lumbar extension and posterior disk herniation. In adolescent athletes, excessive lumbar extension with rotation can cause mechanical stress to the contralateral pedicle and result in lumbar spondylolysis.9 The causative factors for LBP in this age group include lower limb muscle tightness,10 trunk instability,11 excessive lumbar motion,9 and hip–spine incoordination.12 Therefore, the assessment of adolescent LBP during trunk extension is important.

Hip and spine coordination, which is known as the lumbopelvic rhythm (LPR), refers to the concurrent movement of the hip joint and lumbar spine (LS) as they contribute to locomotor function of the lower limbs.13-15 LPR can also be expressed as the lumbar–hip ratio (LHR), which represents the ratio of LS to hip range of motion (ROM), where an LHR ≥1.0 indicates that lumbar motion is greater than hip motion. On the basis of reports on LPR,16 LPR can be evaluated by using a graph with the hip joint angle plotted along the x-axis and the LS angle is plotted along the y-axis. If the LHR does not change, the LPR is appropriate for a linear function. However, no study has reported the LPR or LHR values among adolescent soccer players with and without LBP.

The medical implication of clarifying the LPR and LHR is that it would help with the assessment of lumbar movement in patients with spinal or hip disorders, such as hip–spine syndrome.12 Assessment of lower limb and spinal malfunction can be made according to deviation from the normal ranges of LPR and LHR values only if those normal ranges are known. The purpose of this study was to clarify the effect of LBP on LPR and LHR during trunk extension among adolescent soccer players. The hypothesis was that LBP would affect LS ROM and decrease the LPR and LHR.

METHODS
Participants
This study was approved by the office of research ethics (# 2013-167[1]) at Waseda University. After the team coach gave permission for measurements to be taken, we asked all players to participate in our study. Informed consent was obtained from 119 male soccer players of the town recreation league team. The inclusion criteria were as follows: no prior spine or lower limb surgery, no obvious spinal and lower limb deformities, and no painful lower limb joints. Ten participants were excluded from participating, five participants trunk extension could not be measured and five participants could not perform trunk extension because of pain.

In total, 109 male soccer players (age, 13.1 ± 0.9 years; height, 160.0 ± 9.3 cm; weight, 48.5 ± 8.5 kg; body mass index [BMI], 18.8 ± 1.9 kg/m²) were analyzed. For LBP assessment, a doctor asked participants to perform trunk extension as much as they could and to maintain the maximum position for three seconds in the standing position. The doctor asked each participant if LBP appeared during trunk extension and at end ROM. Based on the findings, the participants were divided into two groups: an LBP group (n = 44; age, 13.1 ± 0.9 years; height, 158.8 ± 9.3 cm; weight, 47.7 ± 8.3 kg; BMI, 18.8 ± 1.8 kg/m²) and a non-LBP group (n = 65; no-LBP; et al.18 reported an LS ROM of 30° measured using a flexicurve technique in soccer players (mean age 12 years). Furthermore, Wong and Lee15 and Tojima et al.16 reported maximum hip ROMs during trunk extension of 15.7° and 17.1°, respectively.
age, 13.1 ± 0.9 years; height, 161.7 ± 9.0 cm; weight, 49.2 ± 8.1 kg; BMI, 18.7 ± 2.0 kg/m²) with and without LBP, respectively.

Devices and procedures
Three-dimensional (3D) motion analysis was performed (Qualysis Track Manager; Qualysis AB., Sweden) at a sampling frequency of 60 Hz, using six cameras were used. All cameras were placed 3.3 m behind the participants; two cameras each were located at the levels of their pelvis, knees, and ankles. A single physical therapist then placed 13 spherical markers, each measuring 14 mm in diameter, on the following anatomical landmarks (Figure 1): thoracolumbar landmarks (spine process of the tenth and twelfth thoracic spines, and the right and left paravertebral muscles at T11), pelvic landmarks (right and left posterior superior iliac spines, and S3), and femoral landmarks (greater trochanter, medial epicondyle, and lateral epicondyle). Measuring lumbar motion with this method has sufficient repeatability (intraclass correlation coefficient ≥.8) and reliability (canonical measure of correlation ≥.99) during trunk extension. The participants were asked to stand with their feet shoulder-width apart and perform trunk extension (without the arms touching anywhere) three times at their own speed. Before measuring their trunk extension, participants practiced trunk extension three to five times. In each participant, the data of three trials were averaged to give a mean test value.

Analytical procedures
Visual3D v5 (C-Motion, Inc., MD, USA) was used for analysis. A low-pass filter at 6 Hz was used to eliminate noise from the raw data. Then, the LS angle from the thoracolumbar segment with respect to the pelvic segment (i.e., the sum of L1–L5 vertebral movements) and the hip joint angle from the femoral segment with respect to the pelvic segment was calculated. The hip joint angle was used to define trunk extension. The start of extension was defined as the point when the hip joint angle was ≥1°, and the end of extension was defined as the point of the maximum hip angle. The LHR was calculated as the ratio of LS ROM to the average of the right and left hip ROM. During trunk extension, decreasing LHR and LPR values indicate decreasing lumbar extension relative to hip extension. After normalizing the phase to 100% using MATLAB (MathWorks, Natick, MA), LHRs were statistically analyzed from 0% to 100% at intervals of 25%.

Statistical analyses
IBM SPSS Statistics, Version 19.0 (IBM Corp., Armonk, NY, USA) was used for the statistical analyses. Paired, two-tailed t-tests were used to compare the LS and hip ROM, as well as the mean LHR, between the non-LBP and LBP groups. Two-way, repeated-measures, analysis of variance was used to analyze time with the LBP and non-LBP groups for LHR. Linear prediction was used to describe LPR, using a graph with the hip joint angle plotted along the x-axis and the LS...
RESULTS

LS and hip ROM
There was no difference in the mean maximum hip ROM between the groups with and without LBP ($p = .376$, 95% confidence interval for difference [CI] = −1.049 to 2.755). Concerning the mean maximum LS ROM, the LBP group had significantly less extension ROM than the non-LBP group, by 6.6° ($p = .005$, 95%CI = 2.086–11.163, Table 1).

Comparison of the LHR between the study groups
There were no differences in LHR between the non-LBP group and the LBP group during trunk extension ($F[4, 428] = 1.840$, $p = .120$). The mean LHRs were 4.6 ± 5.1 and 3.7 ± 3.4 in the non-LBP and LBP groups, respectively (Figure 2 and Table 1). There was no difference in the mean LHR between the groups [$p = .320$, 95% CI = −0.874 to 2.650].

Comparison of the LPR between the study groups
The lumbopelvic rhythm for trunk extension was expressed by a linear function (non-LBP group, $y = 3.2x − 0.4$, $R^2 = .997$, $p < .001$; LBP group, $y = 2.8x − 0.2$, $R^2 = .999$, $p < .001$; Figure 3). According to the linear function, when the hip joint was extended by 1°, the LS extended by 3.2° in the non-LBP group and 2.8° in the LBP group (Table 1).

DISCUSSION
In this study, 3D motion analysis was used to clarify the impact of LBP on LPR and LHR during trunk extension among adolescent soccer players. LBP during trunk extension was shown to be associated with decreased lumbar extension relative to hip extension.

Table 1. The mean parameters of the non-LBP and LBP groups, and other reports.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>non-LBP group</th>
<th>LBP group</th>
<th>Kujala et al.19</th>
<th>Tojima et al.16</th>
<th>Wong and Lee 15</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>flexicurve technique, 19 soccer players</td>
</tr>
<tr>
<td>Age (years)</td>
<td>13.1</td>
<td>0.9</td>
<td>13.1</td>
<td>0.9</td>
<td>.746</td>
</tr>
<tr>
<td>LS ROM (°)</td>
<td>34.8</td>
<td>12.3</td>
<td>28.2</td>
<td>10.8</td>
<td>.005</td>
</tr>
<tr>
<td>Hip ROM (°)</td>
<td>11.0</td>
<td>5.0</td>
<td>10.1</td>
<td>4.8</td>
<td>.376</td>
</tr>
<tr>
<td>Lumbar–hip ratio</td>
<td>4.6</td>
<td>5.1</td>
<td>3.7</td>
<td>3.4</td>
<td>.320</td>
</tr>
<tr>
<td>Lumbopelvic rhythm (°)</td>
<td>3.2</td>
<td>−</td>
<td>2.8</td>
<td>−</td>
<td>−</td>
</tr>
</tbody>
</table>

Abbreviations: LBP = low back pain; LS = lumbar spine; non-LBP = no low back pain; ROM = range of motion.
Previous studies have reported on the LS and hip ROM during trunk extension in adults. The current results for LS ROM in adolescents with LBP are comparable to those in the reports by Kujala et al.18 and Tolima et al.;16 however, the LS ROMs in adolescents without LBP were larger than those reported previously for adults. Overall, it was concluded that LBP inhibited lumbar extension, with LS ROM being smaller in the LBP group than in the non-LBP group during trunk extension. The results for adolescent hip ROM were less in both groups than those reported by Wong and Lee15 and Tolima et al.16 for adults.

It was also considered that potential confounders may have affected the current results. There were large standard deviations for both LS and hip ROMs, with both varying during trunk extension because of inter-individual variability seen in ROM that may have been based on speed. After a few months or a year, participants may or may not have had LBP. However, participants were not observed longitudinally in the current study, so these potential confounders must be considered to have affected the LS and hip ROMs.

The LHR
LBP inhibited LS motion relative to hip extension. Therefore, the LHR was less in the LBP group than in the non-LBP group. However, there was no significant difference in LHR between the groups. The different patterns of trunk extension did not alter the LHR between the two groups. Previously reported LHR values are 1.2–1.9 during trunk extension16 and 1.4 at maximum trunk extension.15 The result for the LHR in adolescents was larger than that reported in previous studies among adults,15,16 because the participants extended their hips less than subjects in previous studies. Furthermore, lumbar extension was greater in the non-LBP group than that in previous studies among adults.15,16

The LPR
LPR was appropriate for linear function because the LHR did not change during trunk extension. The linear function indicated, that when the hip joint was extended by 1°, the LS extended by 3.2° in the non-LBP group and 2.8° in the LBP group. Tojima et al.16 reported, that when the hip joint was extended by 1°, the LS extended by 1.9° in adults. Thus, the adolescent participants extended their LS relative to the hip joint during trunk extension more than adults, consistent with research that adolescent soccer players have tight quadriceps femoris muscles.10 It was presumed that this tightness of the lower limb muscles restricted hip ROM during trunk extension, and that they extended their LS to compensate for the restricted hip motion.

Medical implications
It was shown that LBP inhibits lumbar extension. An elevated BMI in participants may increase the load stress on the LS, but there was only one participant in the current study, in the LBP group, whose BMI was over 24.0, which should not have affected the results. Therefore, a larger LPR could associate with LBP, coaches and athletic trainers should pay attention to high LPR during trunk extension.

Limitations
The limitation of this study was that the current study could not offer suggestions regarding the causative factors for LBP because of the cross-sectional design. Prospective studies are needed that assess other joints and muscle functions if it is going to be explained the relationship between LBP and the LPR during trunk extension.
It was presumed that the lower limb muscle tightness among adolescents may have restricted hip ROM during trunk extension, because compared to adults the adolescent soccer players may have had greater tightness of the quadriceps femoris muscle. In a future study, assessment of muscle tightness around the hip joint would be needed, such as the quadriceps and iliopsoas muscles, which affect hip motion. And, it would be needed to clarify how disk degeneration and spondylolysis affect the LPR during trunk flexion or extension.

CONCLUSIONS

The results of the current study indicate that LBP inhibited lumbar motion relative to hip extension. There was no significant difference between the groups in terms of the LHR. However, the LPR was smaller in the LBP group than in the non-LBP group.

A longitudinal observational study among adolescent soccer players with and without LBP is needed to clarify causative factors contributing to LBP based on the LPR.

REFERENCES

ABSTRACT

Background: The prevalence of radiographic hip osteoarthritis (OA), and its relationship with outcomes after hip arthroscopy is unclear.

Objectives: The aims of this study were to: (i) describe the prevalence of OA and cam deformity 12-24 months post hip arthroscopy; (ii) to determine the association between radiographic OA and cam deformity, surgical and clinical findings and symptoms; and (iii) describe the differences between legs for radiological and clinical findings.

Study Design: Cross sectional study

Methods: Seventy patients, mean age 36.7(range 18-59) years, 12-24 months post-arthroscopy.

Main outcome measures: Outcomes were collected prospectively via clinical and radiographic examination. (i) Prevalence of OA and cam deformity measured on and anteroposterior pelvic radiographs; (ii) Hip disability and Osteoarthritis Outcome Score (HOOS) and International Hip Outcome Tool (iHOT-33) patient-reported outcomes (PROs); (iii) hip internal and external rotation range of motion (ROM). Associations between OA and surgical findings, PROs and clinical findings were determined using generalized estimated equations, between operated and non-operated sides.

Results: The prevalence of OA was 37%. The likelihood of OA 12-24 months after surgery was positively associated with alpha angle size 12-24 months post-hip arthroscopy surgery (p=0.010). There were no differences between operated and non-operated legs in radiographic or clinical findings.

Conclusion: Radiographic OA is prevalent in a population which has undergone hip arthroscopy. Increased OA severity is associated with a higher alpha angle 12-24 months post-surgery.

Level of evidence: Cross-sectional study Level IV

Key words: Alpha angle, femoroacetabular impingement, hip arthroscopy, osteoarthritis

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Conflicts of Interest: None
INTRODUCTION
Hip osteoarthritis (OA) is a common joint disease, with an estimated overall prevalence in the general adult population of 11%. It is a significant cause of pain, stiffness and reduced function in the elderly. Symptomatic OA affects 9.6% of men and 18% of women aged 60 years or older, and with an aging population, the prevalence of OA will increase substantially, which is associated with growing economic, health and personal costs. To date, no cure for hip OA has been found. After OA onset, treatment options, involving non-pharmacological, and surgical treatment, are based on controlling pain, improving function and improving health-related quality of life.

Cam deformity is caused by extra bone formation in the anterolateral femoral head-neck junction and associated with an increased risk of OA. Femoro-acetabular impingement (FAI) is a clinical condition of hip and/or groin pain, associated with abnormal contact between the femoral head-neck junction and the acetabulum, due to a bone shape abnormality on either the femoral (cam impingement) or acetabular (pincer impingement) side. Repeated abutment may cause pain and a cascade of structural damage, resulting in labral tears and cartilage degeneration, ultimately progressing to osteoarthritis of the hip. Therefore, cam deformity and associated impingement has been proposed as a biomechanical risk factor for the development of hip OA.

Hip arthroscopy is now routinely performed for intra-articular hip pathology, including FAI, labral, and chondral pathology. The short term aim of arthroscopic surgery is to relieve pre-operative symptoms including pain and reduced physical function. The long term aim is prevention of repetitive injury to articular cartilage and thus, possibly reducing the risk of subsequently developing OA. Studies have indicated that the prevalence of chondropathy at surgery is 72%. The presence, and severity of chondropathy at the time of surgery is generally associated with poorer outcomes. As FAI is associated with an increased risk of hip OA and its associated symptoms, it is important to determine whether morphology and pathology are also associated with hip OA in people who have undergone hip arthroscopy.

The aims of this study were to: (i) describe the prevalence of osteoarthritis (OA) and cam deformity 12-24 months post hip arthroscopy; (ii) to determine the association between radiographic OA and cam deformity, surgical and clinical findings and symptoms; and (iii) describe the differences between legs for radiological and clinical findings.

MATERIALS AND METHODS
Study design and participants
The study was of cross-sectional design. This study was funded by The Australian Physiotherapy Association, Physiotherapy Research Foundation Beryl Haynes Memorial Fund and was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. This study was approved by The University of Melbourne Human Research Ethics Committee (HREC number 1033063) and The University of Queensland Medical Research Ethics Committee (MREC number 2012000708). The recruitment procedure has been described in detail previously. Between January 2009 and July 2011 all consecutive hip arthroscopy patients, aged between 18-60 years old, of one single orthopaedic surgeon (MGP) were invited to participate in the study. Letters of invitation were sent to patients 12-24 months after their surgery. Participants were excluded if their surgery converted to a total hip arthroplasty (THA), if they had further hip or other surgery or concurrent other lower limb injury, if they were unable to walk without assistance, or if they were unable to speak or read English. From this cohort participants, those who did not consent to have a radiograph taken post-arthroscopy were excluded. All participants provided written informed consent prior to commencing the study.

Procedure
Hip arthroscopy was performed by a single surgeon (MGP) in Hobart, Australia, with the patient in lateral decubitus position, with the hip abducted and slightly flexed while traction was applied. An arthroscope entered the central and peripheral compartments of the hip via a viewing mid-trochanteric portal and an instrument anterior trochanteric portal. The surgical technique used in this study has been reported previously, and used a standardized and systematic technique for the assessment and treatment of
intra-articular pathology, including labral pathology, FAI and chondropathy.\textsuperscript{19}

Collection of this surgical data and collection of clinical, PRO and radiographic data was completed by a single investigator (JLK in a private physiotherapy clinic 12-24 months post-surgery, who was blinded to the surgical findings. Information regarding whether a surgical intervention was performed for intra-articular pathology, including cam deformity, labral pathology and chondropathy, was recorded from surgical notes. The presence of cam deformity at surgery was also noted. Clinical data included hip joint range of motion (ROM). This was measured as internal and external rotation (in 90 degrees of flexion), with a Plurimeter V gravity inclinometer (Dr Rippstein Company, Zurich, Switzerland) described in detail previously.\textsuperscript{23} Patient-reported outcome questionnaire data collected included the Hip Osteoarthritis and Disability Outcome Score (HOOS) and the International Hip Outcome Tool (iHOT-33), which have both been shown to be reliable and valid tools for use in a hip arthroscopy population.\textsuperscript{22}

**Primary outcome measures: Radiographic measures of hip OA and FAI prevalence**

Radiographic imaging 12-24 months post-arthroscopy consisted of scoring anterior-posterior pelvic radiographs for OA severity, using the Kellgren and Lawrence (KL) score and FAI, using the alpha angle. Radiographs were scored by a single investigator (FG) who was blinded to surgical, PRO and clinical data.

**Kellgren and Lawrence score:**

The hip images were graded from the anteroposterior view of the femoroacetabular joint on a scale from 0-4 using the Kellgren and Lawrence (KL) grading system.\textsuperscript{24} Grade 1 and grade 2 K&L grade were classified as early OA, as detectable radiographic OA is considered to represent degenerative joint disease equivalent to OARSI grade 3.\textsuperscript{25}

**Alpha angle**

A cam deformity was quantified by using the alpha angle, which measures the degree of which the femoral head deviates from spherical. The alpha angle was calculated using a point set along the contour of the proximal femur, from which the alpha angle was automatically calculated. This technique has been described previously\textsuperscript{26} and ensures an unbiased measurement of the alpha angle. The alpha angle is measured by first drawing the best fitted circle around the femoral head and then drawing a line through the center of the neck and the center of the head. A second line is drawn from the center of the head to the point where the superior surface of the head-neck junction first departs from the fitted circle. The angle between these two lines is the alpha angle.\textsuperscript{27} The radiographic cam-type deformity is considered to be present when the alpha angle is greater than 60°.\textsuperscript{28}

**Reliability**

The KL scoring and the point set of the SSM software were positioned in all radiographs by one investigator (FG, who was blinded to the other collected data. Reliability of this investigator was tested in 30 randomly selected radiographs of this study against a highly skilled investigator (10+ years experience) from the Erasmus Medical Center (Rotterdam) for the KL score. Reliability for the alpha angle measurements was tested in 40 randomly selected radiographs from the CHECK (Cohort Hip and Cohort Knee) study in Rotterdam, prior to the commencement of this study.

**Statistical analysis**

All statistical calculations were performed using SPSS, version 20.0.0, (SPSS, Chicago, IL). The demographic and clinical characteristics of patients and PRO scores were recorded as means (standard deviation [SD]) and percentages. Multivariate stepwise regression analysis was utilised to determine the adjusted association between patient characteristics, surgical findings, radiographic findings, clinical ROM findings and radiographic OA prevalence. All analyses included covariates of age and gender. Bilateral surgery was accounted for in the analyses where appropriate, using a generalized estimating equation (GEE). The use of generalized estimating equations ensured every hip was an independent subject. Given the multiple testing in a small number of subjects, p<0.01 was considered \textit{a priori} as being statistically significant in regression analyses. The difference between the operated and non-operated leg for radiological and clinical measures
were determined using paired t-tests, in patients who underwent unilateral surgery only. In order to determine a difference between legs of $d = 0.40$ and power of 0.80, a sample of 78 hips was required.

**RESULTS**

Three hundred, fifty-five patients were identified who underwent hip-arthroscopy between January 2009 and July 2011. 152 responded to the invitation, however 52 were excluded (one deceased, nine had moved away, 28 were too busy and four for other reasons); or they had further surgery or other injuries precluding their involvement (four underwent THA, three had other surgery, three had low back pain). Therefore 100 patients fulfilled eligibility criteria for the study. Of the 100 patients who entered the study cohort, 30 were excluded as they did not consent to x-ray post-arthroscopy. Seventy patients were included in this study (78 hips) (Figure 1). Sixty-two patients underwent unilateral surgery and eight patients underwent bilateral surgery. Patient characteristics are summarised in Table 1. The mean age at surgery was 36.7 years (range 18 to 59 years). The median alpha angle was 43 degrees 12-24 months post-arthroscopy. There were 38 female patients (54%). Eight patients (11%) had bilateral surgery, 75% of whom were men with a mean age of 21 years.

**Radiology Findings**

**Reliability**

The kappa score for inter-observer reliability was 0.75 for the KL score. The ICC score for inter-observer reliability for the alpha angle was 0.91.

**Osteoarthritis**

The overall prevalence of early hip OA (K&L grade 1 or 2) was 37%. Of the 78 included hips, 63% ($n = 49$) had no radiographic signs of hip OA (K&L grade 0), 35% ($n = 27$) had very mild radiographic hip OA (K&L grade 1).
grade 1) and 3% (n=2) had mild radiographic hip OA (K&L grade 2) 12-24 months post-arthroscopy.

**Cam impingement**

Thirty one of 78 hips underwent femoral osteoplasty during arthroscopy to treat cam-type FAI diagnosed prior to or at surgery. At 12-24 months post-arthroscopy two men (5%) and one woman (3%) still had a cam deformity out of the group that underwent femoral osteoplasty.

As illustrated in Table 2, post-arthroscopic radiographs showed a statistically significant positive relationship between size of alpha angle and radiographic hip OA post-operatively (p=0.010). A positive trend towards chondral intervention at surgery (p=0.018), labral pathology at surgery (p=0.011) and radiographic hip OA post-arthroscopy was seen (where p<0.01 as determined a priori). Patient characteristics, clinical findings and symptoms were not significantly related to hip OA in this population. The odds ratios (% % CIs) for clinical findings ranged from 0.90(0.83 to 1.02) to 0.99(0.95 to 1.02); while those for symptoms ranged from 0.98(0.96 to 1.01) to 1.00(0.98 to 1.02) (Table 2).

The differences between operated and non-operated leg (n=62 patients who underwent unilateral surgery) for the radiological and ROM outcomes are described in Table 3. There were no significant differences between sides for OA grade, alpha angle, IR ROM and ER ROM.

**DISCUSSION**

The results of this study indicate that radiographic hip OA in its early stages is common, affecting 37% of patients 18-60 years of age post-hip arthroscopy. A larger alpha angle was positively associated with severity of radiographic hip OA post-operatively. Despite unilateral surgery being performed in 62 participants, the operated and non-operated sides had similar ranges of motion and rates of hip OA, with a trend towards lower alpha angles in the operated legs.

Radiographic signs of early onset OA (K&L grade 1&2) were observed in 37% of the patients. Given that detectable radiographic OA (K&L grade 1&2) is considered to represent degenerative joint disease equivalent to at least OARSI grade 25, these findings suggest that the prevalence of early hip OA in this young to middle aged population is high, and has potential to impact pain, function and quality of life in this patient group in the future. Importantly, these findings indicated that older age was not associated with an increased likelihood of OA. In addition, a recent systematic review indicated that patients with mild to moderate hip OA are at greater risk of progressing to THA within two years of the primary hip arthroscopic procedure.21 Patients in this study are at an age of peak work and family commitments yet may be facing a future of degenerative hip disease, associated poor quality of life and eventually THA. Our findings indicate a higher prevalence of radiographic hip OA than the CHECK study, where 24% of the participants were diagnosed with early OA at baseline.11 Given the

### Table 2. Association between parameters and early radiographic OA (n=78 hips).

<table>
<thead>
<tr>
<th>OA parameters</th>
<th>value OR Lower</th>
<th>Higher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labral pathology</td>
<td>0.011 4.25 1.39 12.95</td>
<td></td>
</tr>
<tr>
<td>Chondral intervention</td>
<td>0.018 5.03 1.31 19.30</td>
<td></td>
</tr>
<tr>
<td>Osteotomy</td>
<td>0.468 1.40 .57 3.47</td>
<td></td>
</tr>
<tr>
<td>Radiographic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alpha angle (in degrees)</td>
<td>0.010 1.08 1.02 1.15</td>
<td></td>
</tr>
<tr>
<td>Clinical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROM; ER (90° flexion)</td>
<td>0.483 0.99 .95 1.02</td>
<td></td>
</tr>
<tr>
<td>ROM; IR (90° flexion)</td>
<td>0.289 0.90 .83 1.02</td>
<td></td>
</tr>
<tr>
<td>Symptomatic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HOOS Symptoms</td>
<td>0.237 0.99 .96 1.01</td>
<td></td>
</tr>
<tr>
<td>HOOS Pain</td>
<td>0.486 0.99 .96 1.02</td>
<td></td>
</tr>
<tr>
<td>HOOS ADL</td>
<td>0.280 0.98 .96 1.01</td>
<td></td>
</tr>
<tr>
<td>HOOS Sport and Recreation</td>
<td>0.503 0.99 .98 1.01</td>
<td></td>
</tr>
<tr>
<td>HOOS Quality of Life</td>
<td>0.924 1.00 .98 1.02</td>
<td></td>
</tr>
<tr>
<td>iHOT33</td>
<td>0.475 0.99 .97 1.02</td>
<td></td>
</tr>
</tbody>
</table>

ROM = range of motion; ER = external rotation; IR = internal rotation; P = P-value; OR = Odds Ratio; CI = Confidence interval; * p<0.01.

### Table 3. Differences between operated and non-operated leg for radiographic and ROM outcomes (n=62).

<table>
<thead>
<tr>
<th>measured</th>
<th>(mean[SD])</th>
<th>side</th>
<th>sides (95% confidence interval; p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha angle</td>
<td>44[8]</td>
<td>47[11]</td>
<td>-3 (-6 to 1; p=0.055)</td>
</tr>
<tr>
<td>External rotation</td>
<td>36[10]</td>
<td>36[9]</td>
<td>0 (-2 to 2; p=0.799)</td>
</tr>
<tr>
<td>Internal rotation</td>
<td>31[11]</td>
<td>33[8]</td>
<td>-2 (-4 to 1; p=0.223)</td>
</tr>
</tbody>
</table>

SD = standard deviation; p=0.05; K&L – Kellgren and Lawrence; ROM = range of motion.
The mean age of this cohort (37 years), and our recent finding of a risk of progression to THA in patients with hip OA at arthroscopy, these findings raise concerns regarding the long-term hip joint health in this patient group.

Patient-reported outcomes of pain and function in this study were not associated with radiographic hip OA in the current study. Previous studies have reported an inconsistent relationship between early radiographic OA and patient characteristics, clinical findings and symptoms. Given previous findings where more severe cartilage disease predicted worse PROs in patients post hip arthroscopy, and patients with chondrolabral pathology had worse impairments in strength and range of motion, it appears that more sensitive imaging measures to early stages of disease may be required, in order to identify factors that can alter hip joint disease progression. Imaging using 3.0T magnetic resonance imaging (MRI), scored using a semi-quantitative system such as the Scoring Hip OA with MRI (SHOMRI) can identify features of early hip OA. These include bone-marrow oedema, subchondral cysts, articular cartilage defects, paralabral cysts, and labral pathologies, all of which correlate with clinical features of hip OA. The application of such measures into clinical practice may assist in this process in future.

A larger alpha angle was significantly associated with greater hip OA post-surgery. While the odds ratio was small (8% increased likelihood of OA in larger alpha angles), the narrow confidence intervals suggest the findings are precise, with the true effect somewhere between 1% and 15%. Future studies may choose to follow patients up beyond 24 months to explore this relationship. In post-operative knee injured groups, the onset of radiographic knee OA generally occurs 10-years after surgery, and it is possible similar time periods are needed to observe the onset of radiographic hip OA in people with cam morphology after hip arthroscopy surgery. In addition, when chondral or labral interventions were performed at the time of surgery, patients were four to five times more likely to have early radiographic OA, although these findings were not statistically significant (where p<0.01). Given the wide confidence intervals associated with these findings, it is likely that the true association may be closer to the lower CI (30%) for each of these findings. These findings appear to support previous work, which indicated a greater likelihood of chondral pathology when FAI or labral pathology were present at surgery, suggesting that patients with FAI and labral pathology represent hip OA in its early stages. To date, the efficacy of surgical and non-surgical interventions for altering hip joint disease progression remain unknown. These interventions require further investigation in high quality randomised controlled trials in order to determine the most efficacious treatments to slow hip joint disease progression in these patients.

There were no significant differences between the operated and non-operated leg for radiographic and ROM outcomes in the current study. Interestingly, there was also no association between ROM outcomes and radiographic hip OA. To the best knowledge of the authors, these findings have not been reported previously. Hip arthroscopy surgery may aim to reduce the size of the cam deformity (alpha angle) and thus improve hip joint ROM in patients with cam-type FAI. Given that we found no difference between operated and non-operated sides after unilateral hip arthroscopy surgery, in alpha angle or joint ROM, and no relationship between ROM and radiographic hip OA, it is possible that limits to joint range may be influenced by factors other than cam deformity size. These could include soft-tissue structures around the joint, and other morphological variants such as acetabular or femoral version. This study finding of reduced ROM not being associated with radiographic OA is in contrast to other studies. This may be because the study quantified radiographic OA only, and did not classify patients based on measures of clinical OA, that were used in previous studies. Studies measuring pre-operative to post-operative change in these parameters are needed to confirm this hypothesis.

The current study has some limitations. Firstly, the authors did not obtain pre-operative radiographs and therefore could not compare the pre-arthroscopic with the post-operative radiographs to compare osteoarthritic changes, or changes to the alpha angle following osteoplasty. Future studies should attempt to examine the change in OA between
the pre- and post-operative time points. Second, surgical outcomes were retrieved from the surgical notes of a single surgeon, potentially limiting the generalizability of these findings. However, a standardised and previously published surgical technique was used enhancing the reproducibility of these findings. Third, there were a small number of participants with radiographic hip OA (n = 29) included in the regression analyses. Given this number, it was decided to use a p-value of 0.01 to delineate statistical significance. Associations between radiographic hip OA, and chondral or labral intervention neared statistical significance. Future studies with larger numbers may determine stronger associations between radiographic hip OA and these other parameters in this patient group. Patients were excluded from the study who had undergone total hip arthroplasty following the hip arthroscopy procedure. If these patients were included, the prevalence of hip OA may have been higher than that reported. Finally, 30 out of 100 people did not consent to x-ray, creating the possibility of inclusion bias. However, between-group analysis of participant characteristics of those included to those not included revealed no differences, providing confidence that the cohort included is representative of the whole group.

CONCLUSION
In conclusion, radiographic early OA is prevalent in a population who are 12-24 months post-hip arthroscopy and is positively associated with a larger alpha angle post-arthroscopy. Further prospective longitudinal studies are required to determine the influence of FAI and the arthroscopic intervention on the development of hip OA.

REFERENCES


ABSTRACT

**Background:** Dry needling (DN) has been established as an effective treatment for myofascial pain, however, there are no studies thus far investigating the benefit to movement and motor control.

**Purpose:** The primary purpose of this study was to compare differences in a series of outcomes between dry needling, dry needling and stretching, and stretching only in a sample of healthy males. A secondary purpose was to compare change over time.

**Design:** Blinded, randomized controlled trial

**Methods:** Thirty healthy male subjects were randomly assigned to one of three intervention groups: DN, stretching, or combination DN + stretching. Subjects in the DN group and DN+stretch group received DN to a palpated trigger point (TrP) in the triceps surae to elicit local twitch response. Subjects in the stretch group and DN+stretch group were instructed in a home stretching program for gastrocnemius and soleus muscles. All groups were tested for dorsiflexion range of motion and performed functional tasks (overhead deep squat, and Y-Balance test, Lower Quarter) prior to intervention, directly after intervention, and four days post intervention. Group comparisons were performed using a repeated measure Analysis of Variance and a partial eta squared calculation for effect size. For all measures a p-value of <0.05 was used to determine significance. Cohen's criteria were used to categorize strength of effect size.

**Results:** There were no statistically significant differences among groups for range of motion nor functional measures, with the exception of the deep squat. Proportionally, the DN group improved significantly in deep squat performance (p<0.01) compared to the other groups. Time oriented improvements were seen for the YBT posterior-lateral reach (p=0.02) only. Between groups effect sizes ranged from 0.02 (small) to 0.17 (large).

**Conclusions:** Including DN did not markedly influence range of motion nor functional assessment measures, excluding those seen during the overhead deep squat. Effect measures suggest the lack of significant findings may be an issue of statistical power.

**Level of Evidence:** 1b

**Key Words:** Deep squat, dry needling, range of motion, stretching, triceps surae
INTRODUCTION
Dry needling (DN) is considered a safe and effective method to decrease pain and improve function by eliciting a local twitch response in the muscle of the myofascial trigger points (TrP). Several recent studies have been published related to the role of dry needling and its benefits in treating upper quarter pain. Osborne and Gatt demonstrated that TrP dry needling was effective in reducing shoulder pain and improving shoulder function in elite female volleyball players. Dry needling has also been shown to be an effective treatment for lateral epicondylitis as well as in patients with chronic shoulder impingement syndrome who had previously failed conservative management. Following a recent meta-analysis and systematic review conducted by Kietrys et al, dry needling was recommended over sham or placebo, for decreasing pain immediately after treatment and for a duration of four weeks in patients with upper-quarter myofascial pain syndromes. In addition, dry needling has been used in conjunction with traditional physical therapy interventions for treatment of adhesive capsulitis, resulting in significantly reduced pain and improved range of motion.

Lower extremity pain and function have also been studied in relation to dry needling. Mayoral, et al reported that a single pre-surgical dry needling treatment of myofascial TrP under anesthesia resulted in a significant reduction in pain the first month after knee arthroplasty. Furthermore, significant clinical improvements were demonstrated in pain, tenderness, and function when combining DN, eccentric loading of the hamstrings, and lumbopelvic stabilization exercises in runners with proximal hamstring tendinopathy. Dry needling has also been reported as part of a multimodal manual therapy intervention for treatment of chronic femoral acetabular impingement that did not respond to prior surgical or non-surgical treatments. More recently, the effects of dry needling in the lower extremities are being studied in the neurological population. Salom-Moreno et al found that a single session of dry needling decreased spasticity as well as widespread pressure pain sensitivity in subjects with spasticity post stroke.

Although research surrounding dry needling continues to grow, the current literature focuses on addressing pain as the primary research outcome. There have been no studies specifically observing change in functional outcome measures following the intervention. At present, there are no studies that have specifically targeted triceps surae. The triceps surae complex includes both the gastrocnemius and the soleus muscles with attachments proximally at the posterior knee and distally at the posterior ankle. Restrictions in this muscle have been linked to knee pain, ankle/heel pain, and difficulty performing functional tasks such as squatting and lunging. In addition, the triceps surae assist in control of the knee and ankle and thus, play a role in all lower extremity activities including walking, running, jumping and sports participation. The presence of TrP is linked to overuse of muscles as well as inappropriate use of muscles. In the present study, the triceps surae muscle was chosen to assess as it is used during exercise as well as daily activities and thus has a high likelihood of TrP presence. The purpose of this study was to compare differences in a series of outcomes in a sample of healthy males between dry needling, dry needling and stretching, and stretching only, when dry needling was targeted to the triceps surae. A secondary purpose was to explore the influence of time on outcomes. It was hypothesized that the individuals in dry needling and dry needling + stretch group would experience improvements in dorsiflexion measurements and squat patterns over the stretching group.

METHODS
Consort Guidelines: This study used the Consort guidelines for reporting of randomized trials. Refer to Figure 1 for flow of study enrollment.

Study Design: The study was a randomized controlled trial with three groups and equal allocation potential for each group.

Subjects: Healthy male subjects between the ages of 18 and 30 were recruited via word of mouth to participate in this study. To create a homogenous group of subjects, a single sex was recruited. Males were chosen for this study as evidence exists that males demonstrate more gastrocnemius stiffness than females when measured via shear wave elastography. Individuals were included if they were healthy and physically active at least three times
per week for at least 30 minutes per bout of exercise (each subject completed a MARX Activity Questionnaire to quantify activity level (4 = least active, 16 = most active). Subjects were excluded if they had a history of ankle surgery or were being currently treated for any lower body injury. Subjects were also excluded if they had any precautions for dry needling including: hypothyroidism, connective tissue disorders, chronic pain, bleeding disorders, taking anti-coagulants, active cancer, local or systemic infection, local skin lesion, local swelling/lymphedema, peripheral vascular disease including varicose veins, compromised immune system, and/or fear of needles. All subjects signed an informed consent form that had been approved by the Duke University Health System Institutional Review Board prior to study initiation.

Sample Size: To determine sample size, the authors powered the study (a-priori) for all ten outcomes measures including pre-test, post-test and follow up periods. Assuming a normal distribution of the dorsiflexion measures and assuming an effect size of 0.67 (large) favoring both dry needling groups over the stretch only group, the authors constructed a sample size estimation using a repeated measure, analysis of covariance (RM-ACNOVA). Measuring between groups differences, with an expected 80%
power, 3 dedicated time intervals (including baseline), eight outcomes measures, three independent groups, and a standard error of probability of 0.05, it was estimated that the need for a minimum sample size of 30 for statistical significance (~10 per group). Further, the authors did not oversample characteristics within each group for drop-outs.

Randomization Sequence: Subjects were randomly assigned via number generator to one of three treatment groups: 1) dry needling-only, 2) stretching-only, or combination dry needling + stretch.

Outcome Measures: The following outcomes were captured at baseline (pre-test), immediately after administration (post-test) and at a three day follow up: passive dorsiflexion (Figure 2), closed chain half kneeling dorsiflexion (Figure 3), closed chain (weight bearing) dorsiflexion (Figure 4), and deep squat. These procedures are described in Table 1. Also at baseline, post-intervention, and at the three day follow up, the Y-Balance Test of the Lower Quarter (YBT-LQ) was administered per the protocol described by Gorman to assess functional dorsiflexion and dynamic balance. From these outcomes, the variables of interest were changes in DF...
Table 1. Outcome measures and details of administration.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Description of procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive Dorsiflexion</td>
<td>The subject assumes a prone position with the leg being measured flexed to 90 degrees. The investigator passively dorsiflexes the foot to end range while maintaining a neural foot. An inclinometer placed along the 5th metatarsal measures the maximal dorsiflexion achieved. (Figure 2)</td>
</tr>
<tr>
<td>Closed Chain Half Kneeling Dorsiflexion</td>
<td>The subject assumes a half kneeling. He is asked to lean his body weight forward as far as possible without lifting the heel. An inclinometer placed along the tibia of the forward leg, just distal to the tuberosity, measures the maximal dorsiflexion achieved. (Figure 3)</td>
</tr>
<tr>
<td>Closed Chain Standing Dorsiflexion</td>
<td>The subject assumes a split stance position. He is asked to lean his body weight forward as far as possible without bending the knee or lifting the heel. An inclinometer placed along the tibia of the rear leg, just distal to the tuberosity, measures the maximal dorsiflexion achieved. (Figure 4)</td>
</tr>
<tr>
<td>Deep Squat</td>
<td>As described by Cook, et al in FMS procedures. 22 Subject assumes a standing starting position with feet shoulder width apart and in the sagittal plane. A dowel is held overhead. He is asked to squat as deep as possible while maintaining an upright torso. If he can do this with the trunk parallel to the tibia, the dowel behind the toes, the heels down, and the hips below the knees he scores a 3. If he can perform this correctly with a heel lift, he scores a 2. If still unsuccessful, he scores a 1. If he has pain, he scores a 0 regardless of performance. (Figure 5 a-c)</td>
</tr>
</tbody>
</table>

Figure 5. The Overhead Deep Squat as described and scored by the Functional Movement Screen™. (a) Score of 1, (b) Score of 2, (c) Score of 3.
range of motion in the three described positions, the improvement in deep squat score, and the asymmetry between limbs for each reach direction and normalized composite score of the YBT-LQ. The physical therapists collecting outcomes were blinded to the treatment that each subject received and did not perform any interventions. Measures were collected bilaterally and later coded as “intervention side” and “non-intervention side” for all groups. In the stretch group, which included bilateral intervention, the side with the greatest DF restriction was chosen as the “intervention side” as this was the same criteria used to determine the side of intervention in the DN groups.

Interventions: Subjects in the DN group were positioned in prone and each gastrocnemius and soleus muscles were palpated for presence of TrP. The laterality of the intervention was chosen based on which limb demonstrated the most prominent trigger points as well as the most restricted passive dorsiflexion. The trigger point was assessed using the approach described by Dommerholt. Once the location of a trigger point was established, each subject in the DN group received DN using a .30 x 5cm single-use-needle to the trigger point to elicit a local twitch response. The DN pistoning technique was performed as described in Trigger Point Dry Needling: An Evidence and Clinical Based Approach. The single DN treatment was performed by the same physical therapist under musculoskeletal ultrasound which allowed for visualization of a local twitch response for each subject. Subjects in the stretch group (n = 11) were instructed in a home stretching program for gastrocnemius and soleus muscles. Subjects were instructed to stretch the gastrocnemius by positioning the back foot in a straight line with toes pointing towards the wall and leaning toward the wall with the back knee straight while keeping the heel on the ground. The same procedure was used for the soleus stretch with the exception of instructing the subject to bend the back knee when leaning forward. Each stretch was performed barefoot and was held for 30 seconds and repeated three times on each leg. Each subject performed the stretching program in its entirety at the test site and twice daily until the final follow up at four days post-intervention. Subjects recorded their compliance on a provided handout. The combination group received trigger point dry needling to triceps surae using the procedure listed above. They were then instructed to follow the same stretching program. DN was performed unilaterally to assess the central nervous system response. However, stretching was performed bilaterally to elicit a peripheral change. Immediately following intervention, all subjects were tested in the same manner as listed in the following paragraph. For blinding purposes, each subject, regardless of intervention group, was provided an adhesive bandage to wear during post-testing and was instructed to refrain from revealing which intervention he received. All stretches were performed bilaterally while dry needling was performed on a single side. All subjects returned after three days for re-testing.

Statistical Methods: Descriptive statistics were used to describe the healthy subjects across the three groups. A Repeated Measures ANCOVA was used to measure differences among times (post-test and follow-up), between the three groups (dry needling only, stretching only, and dry needling and stretching), and the group*time interactions among the unique multiple range of motion and functional outcome measures. The authors controlled for baseline measures of range of motion and functional scores. Partial eta squared, the effect size measure for an analysis of variance or covariance for between group changes, was calculated. According to Richardson and Cohen partial eta squared values of .0099, .0588, and .1379 represent effect magnitudes of small, medium, and large sizes, respectively.
Because deep squat change scores were categorical, a Fisher exact test was used to calculate differences among groups at post-test and follow up intervals. A p-value of 0.05 was considered statistically significant. The categories were defined as the number of subjects who did improve and the number of subjects who did not improve across the three groups.

**RESULTS**

Thirty males participated in the study with no subjects lost to follow up. All subjects receiving the dry needling intervention were observed to demonstrate a twitch response via palpation which was visualized on musculoskeletal ultrasound. The groups required to stretch were one hundred percent compliant via the self-report home program documentation. Across the three intervention groups, the subjects were an average age of 26.41 ± 3.14 years and an average body mass index of 25.27 ± 4.36 kg/m². The median MARX Activity score was 10.0 (25, 75 quartile = 8, 13). There were no baseline differences across the groups in any category (Table 1).

Individuals in the DN group exhibited a significant improvement in performance of the overhead deep squat when compared to those in the stretch and the DN+stretch group at immediate post-testing (p=0.01) and testing three days later (p<0.01) (Table 3). There were no significant differences in performance among groups for YBT-LQ or range of motion measures (Table 4). A significant influence of time was identified for the physical function measure of YBT-LQ, posterior-lateral reach (p=0.02) only. As with the range of motion measures, no time*group interaction for any of the functional measures were observed. Partial eta squared measures ranged from 0.02 (small) to 0.16 (large).

There were no significant differences among groups for range of motion measures (Table 2). There were no significant differences between the two time points either. Further, no time*group interaction were found for any of the range of motion measures. Partial eta squared values ranged from a low of 0.05 (small) to a high of 0.17 (large).

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (years)</th>
<th>Height (inches)</th>
<th>Weight (pounds)</th>
<th>MARX Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>DN</td>
<td>25.1 ± 2.4</td>
<td>70.3 ± 2.2</td>
<td>176.8 ± 23.8</td>
<td>10.4 ± 3.6</td>
</tr>
<tr>
<td>Stretch</td>
<td>27.1 ± 4.9</td>
<td>70.3 ± 3.2</td>
<td>192.5 ± 38.2</td>
<td>1.5 ± 3.3</td>
</tr>
<tr>
<td>Stretch + DN</td>
<td>23.3 ± 4.8</td>
<td>70.3 ± 8.3</td>
<td>175.8 ± 22.7</td>
<td>8.7 ± 4.7</td>
</tr>
</tbody>
</table>

DN= Dry needling

### Table 2. Subject Demographics.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Groups</th>
<th>Immediate Follow Up</th>
<th>3 Day Follow Up</th>
<th>Within-Groups P value (Time)</th>
<th>Between-Groups P value (Group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Squat</td>
<td>DN+Stretch</td>
<td>8=No change</td>
<td>1=change</td>
<td>0.01</td>
<td>8=No change</td>
</tr>
<tr>
<td></td>
<td>DN only</td>
<td>5=No change</td>
<td>5=change</td>
<td></td>
<td>4=No change</td>
</tr>
<tr>
<td></td>
<td>Stretch only</td>
<td>11=No change</td>
<td>0=change</td>
<td></td>
<td>11=No change</td>
</tr>
</tbody>
</table>

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DISCUSSION

This study examined both immediate and short-term effects of dry needling on DF range of motion and functional movement patterns in healthy individuals. The investigators hypothesized that both the DN and DN+Stretch group would have greater improvements in range of motion, dynamic balance, and functional squat over stretching alone. Although no statistically significant differences existed between groups for the majority of the outcomes, a higher proportion of individuals in the DN groups did improve in categorical scoring of the overhead deep squat. Further, for non-categorical measures, medium or large between group effect sizes in five of the seven non-categorical measures were identified.

Significant changes in the overhead deep squat score were present both immediately after DN intervention and at the three day follow up in comparison to the other two intervention groups. Changes were observed in the DN+S group, although these were not statistically significant. Although the study was powered using a RM ANCOVA and large effect, the authors feel that one of the reasons the study did demonstrate statistically significant differences is the sample size. Partial eta square measures the proportion of the total variance in a dependent variable that is associated with the effects of other independent variables and interactions are adjusted in the model. Similar to Cohen's D, which provides a magnitude measure of difference between groups, a partial eta squared is designed to provide an assessment magnitude of difference among the three groups in our study. Half-kneeling, YBT anterior and posterior-medial reach all yielded large effect differences between groups, descriptively favoring the DN group.

Interestingly, there were no subjects in the stretch only group that demonstrated change in deep squat

| Table 4. Immediately post, and 3-day follow-up measures proxy measures of physical function (N = 30). |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Outcome                        | Groups                          | Immediate Follow Up | 3-day Follow Up | Within-Groups p-value (Time) | Between-Groups p-value (Group) | Partial Eta Squared |
| YBT-Balance Composite Score (%)| DN+Stretch                      | 100.53 (6.52)       | 100.52 (7.92)   | 0.10                          | 0.31                          | 0.08               |
|                                | DN only                         | 102.12 (4.78)       | 104.36 (7.13)   |                               |                               |                   |
|                                | Stretch only                    | 97.86 (6.48)        | 99.63 (6.64)    |                               |                               |                   |
| YBT-Balance Anterior Reach     | DN+Stretch                      | 1.72 (1.54)         | 2.78 (2.51)     | 0.98                          | 0.15                          | 0.14               |
|                                | DN only                         | 4.23 (2.42)         | 3.83 (1.96)     |                               |                               |                   |
|                                | Stretch only                    | 4.54 (3.85)         | 3.18 (2.70)     |                               |                               |                   |
| YBT-Balance Posterior-Lateral Reach | DN+Stretch   | 3.60 (3.76)         | 3.25 (2.17)     | 0.02                          | 0.53                          | 0.05               |
|                                | DN only                         | 3.72 (4.50)         | 3.72 (3.42)     |                               |                               |                   |
|                                | Stretch only                    | 3.72 (4.75)         | 5.31 (4.19)     |                               |                               |                   |
| YBT-Balance Posterior-Medial Reach | DN+Stretch | 4.60 (2.90)         | 2.80 (2.05)     | 0.32                          | 0.08                          | 0.17               |
|                                | DN only                         | 4.38 (2.51)         | 6.11 (5.64)     |                               |                               |                   |
|                                | Stretch only                    | 2.18 (1.00)         | 3.50 (2.58)     |                               |                               |                   |
The deep squat requires bilateral functional dorsiflexion yet this improved in the DN group and to a lesser extent the DN+S group, both of which received unilateral intervention. This may be attributed to the neurophysiological response of the spinal reflex that occurs during dry needling when twitches are elicited, thus enabling bilateral effects from a unilateral treatment. It has been established that TrP, both active and latent, affect movement via muscle activation patterns. In addition, dry needling of a myofascial trigger point is effective in diminishing spontaneous electrical activity of that point if local twitch responses are elicited. When spontaneous electrical activity of the muscle is diminished a more normal muscle state is achieved. Authors have also shown that latent trigger points provide nociceptive input to the dorsal horn even when they are not spontaneously painful which may explain the observed changes in functional movement patterns following dry needling.

DF ROM has been linked to performance of functional tasks. Prior studies have shown limitations in dorsiflexion, as measured in weight bearing, as an indicator of decreased performance. Rabin et al assessed DF range of motion in a lateral step-down test among healthy males and found association between ankle DF range of motion and movement quality among men. More specifically a 'good quality' movement pattern, as seen during the lateral step-down test, indicated greater DF range of motion. Thus, it is likely that multiple factors influencing DF range of motion can also affect weight bearing movement patterns. Kang et al further confirmed that functional performance may be altered with limitations in DF, as determined by the weight bearing lunge test. Specifically, the anterior reach distance on the lower quarter Y-balance test was significantly correlated to DF measured via the weight bearing lunge test. Thus, one can infer that ankle kinematics can affect performance during weight bearing tasks. In the current study, subjects did not demonstrate significant improvement in composite score or reduction in reach asymmetry with the exception of the posterolateral reach direction which showed improvement over time. With a larger sample size, significant changes in anterior reach, posteromedial reach, and composite score performance may have been observed as the effect size for both anterior and posteromedial reach distance was large.

There were several limitations to this study. First, this study enrolled healthy subjects rather than a patient population thus limiting potential application to the typical clinical setting. Also, these subjects did not demonstrate significant restrictions in initial ankle dorsiflexion range of motion (where normal range is between 0-16 degrees in non-weight-bearing and up to 34 degrees in weight bearing). Thus, the investigators, were not fully able to appreciate the influence DN may have on limited DF. Second, the mechanism causing dorsiflexion end range of motion was not determined. So, it is unknown if the restrictions were due to tissue extensibility or joint restrictions. Future research may compare groups with and without dorsiflexion restrictions and the effect on functional movement patterns pre and post dry needling.

In addition, studies with longer follow up are needed to establish long term benefits of dry needling compared to dry needling/stretching combination or stretching programs alone as the current study's follow up ended at three days post intervention. The current study included only a single dry needling treatment, as is typical in clinical practice, rather than three consecutive days of dry needling treatment. Additional dry needling sessions, matching the frequency of the prescribed daily stretching sessions, may have yielded different results. Future iterations of this study should employ shear wave elastography to observe and objectify changes in trigger point size pre and post DN. Furthermore, research is needed to establish long term maintenance of changes in functional movement patterns that may have been affected.

CONCLUSION
Dry needling to an identified TrP in the triceps surae in healthy males resulted in both immediate and short-term changes in the overhead deep squat pattern. Including DN did not markedly influence range of motion and functional assessment measures, apart from the squat. Effect sizes suggest moderate to large effects from the DN treatment despite the lack of statistically significant differences, meaning some results may be due to insufficient power.
REFERENCES


ABSTRACT

**Background:** Achilles tendinopathy negatively affects a person's ability to be physically active. However, remaining physically active during the rehabilitation process does not impact clinical outcomes when a pain-monitoring model is followed. There are several factors, such as the progression of pain and structural changes, kinesiophobia, functional impairments, or medical advice, which may explain why some patients become physically inactive while others maintain a physically active lifestyle.

**Purpose:** The purposes of this study were 1) to compare the clinical presentation of patients with Achilles tendinopathy with high and low activity levels 2) to examine the relationship between tendon thickening and symptom severity in patients with Achilles tendinopathy and 3) to determine the proportion of patients with Achilles tendinopathy who have a high degree of kinesiophobia and if this proportion differs based on activity level.

**Study Design:** Cross-sectional

**Methods:** Fifty-three patients with Achilles tendinopathy were dichotomized into low activity (n=30) and high activity (n=23) groups based on their physical activity level. Patient characteristics, symptom severity, kinesiophobia, tendon thickening, and lower leg function were quantified and analyzed to test the study hypotheses.

**Results:** Patients with low activity levels had greater tendon thickening and a larger body mass compared to patients with high activity levels. There were no differences in symptom severity, kinesiophobia, or lower leg function between groups. A negative relationship \( r=-0.491; p<0.001 \) was found between tendon thickening and symptom severity. Thirty-eight percent of patients demonstrated a high degree of kinesiophobia, but the proportion did not differ between groups.

**Conclusion:** Patients with Achilles tendinopathy who have low physical activity levels demonstrate greater tendinosis than patients who are highly active. These structural changes are negatively associated with symptom severity. However, symptom severity, kinesiophobia, and functional deficits do not differ between patients with different activity levels.

**Level of evidence:** Level 3

**Key words:** Achilles tendon, kinesiophobia, physical activity, tendon structure

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**Conflicts of Interest:** The authors have no conflicts of interest to report

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INTRODUCTION

Achilles tendinopathy is a clinical syndrome characterized by pain, swelling, and impaired functional performance.\(^1\) It has a reported incidence rate of 2.35 per 1000 in the adult population\(^2\) and frequently affects people who are highly physically active and people who have recently modified their physical activity.\(^3,4\) These people may be able to continue their physical activities throughout the early stages of the injury, but as symptoms progress, their ability to participate in physical activities is negatively affected.\(^5\) This reduction in physical activity not only impacts a patient socially, but also has discernible psychological effects\(^6\) and can negatively affect overall health and quality of life.\(^7\) Since the primary goal for many patients with Achilles tendinopathy is to safely return to their physical activities, it is important to understand what factors hamper their ability to maintain a physically active lifestyle.

Historically, patients with chronic Achilles tendon pain were recommended by medical professionals to rest, take anti-inflammatory medication, and avoid physical activities that caused symptoms.\(^8,9\) This approach was commonplace when Achilles tendon pathology was thought to be an inflammatory process, but pivotal evidence\(^10,11\) has since revealed that this pathology is degenerative in nature, not inflammatory. With this paradigm shift from inflammatory to degenerative, both terminology and treatment for chronic Achilles tendon disorders have changed. The term “tendinitis,” which refers to inflammation of the tendon, has been largely abandoned and replaced with “tendinopathy.”\(^1\) Tendinopathy is a clinical syndrome that is diagnosed based on patient history and findings on physical exam.\(^1\) Furthermore, when a patient with tendinopathy undergoes diagnostic imaging or histologic evaluation, a diagnosis of tendinosis can be made if the tendon’s structure is altered (e.g. increased thickness and/or cross-sectional area) or if histopathological manifestations are found that suggest tendon degeneration (e.g. abnormal collagen fiber structure, hypercellularity, and increased vascularity).\(^12,13\) Tendinosis however does not imply pain and occurs in both symptomatic and asymptomatic individuals.\(^1\)

In addition to changes in terminology, treatment for chronic Achilles tendon pathology has shifted away from rest and towards exercise therapy, which promotes tendon healing through mechanical stimuli (i.e. mechanotherapy or mechanotransduction\(^14,15\)). Effective loading programs have been established\(^16-20\) and were recently compared in a systematic review by Malliaras et al.\(^21\) Two commonalities exist between these loading programs: 1) the tendon is loaded and 2) pain is allowed to increase to a certain degree during the exercises. Taken together, these two characteristics demonstrate the importance of loading the tendon during treatment and using pain to ensure loads are adequate enough to cause positive adaptive changes. This treatment approach was further supported in a randomized-controlled trial by Silvernagel et al.\(^20\) who found no detrimental effect of allowing patients with Achilles tendinopathy to continue activities that involved running and jumping during the treatment process as long as they adhered to a pain-monitoring model. These findings illustrate that patients with Achilles tendinopathy can be physically active during treatment, but it remains unclear what causes people with Achilles tendinopathy to reduce their physical activity levels in the first place.

There may be several reasons why patients with Achilles tendinopathy reduce their physical activity levels, including the progression of symptoms and structural degeneration, kinesiophobia, functional impairments, or following advice from a medical professional. Depending on which of these variables are contributing to decreased physical activity, treatment modification may be required to enable a safe return to physical activity participation. Therefore, it is important to determine the differences between patients with Achilles tendinopathy who have high levels of physical activity and those who have low activity levels (i.e. fall below the recommended 150 minutes per week of moderate to vigorous physical activity\(^22\)).

The purposes of this study were 1) to compare the clinical presentation of patients with Achilles tendinopathy with high and low activity levels 2) to examine the relationship between tendon thickening and symptom severity in patients with Achilles tendinopathy and 3) to determine the proportion of patients with Achilles tendinopathy who have a high degree of kinesiophobia and if this proportion differs based on activity level. It was hypothesized that patients with low physical activity levels at the
time of evaluation would present with greater symptom severity and degree of kinesiophobia, but not necessarily have greater tendinosis or functional impairments compared to patients with high physical activity levels. It was also hypothesized that the degree of tendon thickening would be related to symptom severity in patients with Achilles tendinopathy and the proportion of patients with high kinesiophobia would be greater in patients with low levels of physical activity compared to those with high levels of physical activity.

METHODS

Study Design

All patients in the current study were recruited as part of a larger longitudinal study looking at various Achilles tendon injuries (e.g. midportion tendinopathy, insertional tendinopathy, rupture). The current study is cross-sectional and only includes patients with midportion Achilles tendinopathy. All data were collected during the patient's baseline visit. All 153 patients who were enrolled in the larger longitudinal study from November 2014 to February 2017 were screened against the current study criteria. Approval for this study was obtained from the institutional review board at the University of Delaware. All participants received verbal and written information about the study and consent was obtained.

Patients

Inclusion/Exclusion Criteria

In order to be included in the current study, patients were required to be at least 18 years of age and have a primary clinical diagnosis of midportion Achilles tendinopathy. Criteria for diagnosis were 1) pain with palpation to midportion of the Achilles tendon (i.e. 2-6 cm proximal to calcaneal insertion) 2) reported pain that increased with loading activities 3) focal or diffuse swelling 4) altered functional status (e.g. inability to perform high-demand activities, self-reported calf muscle weakness or impaired endurance). Diagnosis was confirmed by a licensed physical therapist with a patient interview and physical examination. Patients were excluded from the study if they had a history of Achilles tendon rupture or did not complete the questionnaire necessary for group allocation. Of the 153 patients in larger longitudinal study, 53 fit the current study criteria.

Classification of Physical Activity Levels

Each patient's current level of physical activity was quantified with a physical activity scale (PAS) (Table 1) as originally described by Grimby and previously used in clinical trials involving patients with Achilles tendon injury. Using the patient's current PAS score and the United States national guidelines for physical activity, which states that adults should perform 150 minutes of moderate to vigorous intensity exercise each week as our cutoff, patients were dichotomized into high activity (PAS≥5; n=23) and low activity (PAS<5; n=30) groups. In addition to using current PAS scores for group allocation, patients were also asked to indicate PAS scores for their activity level prior to injury (Table 1).

Patient Reported Outcomes

The Victorian Institute of Sport Assessment- Achilles questionnaire (VISA-A) was used to evaluate symptom severity of the patient's Achilles tendon injury. The VISA-A is a measurement tool with good validity and reliability that contains eight questions that...
are scored from 0 to 100, with a score of 100 indicating symptom-free and physically active. Due to inherent differences between groups with respect to physical activity levels, scores from questions 7 and 8 were subtracted from the overall score as they pertain to current physical activity levels. This led to a maximum possible score of 60. Both the overall VISA-A and the adjusted VISA-A scores are reported to allow for comparisons to previous literature; however, only the adjusted VISA-A score was used in the interpretation of group differences.

Kinesiophobia was quantified using the Tampa Scale for Kinesiophobia (TSK). This questionnaire contains 17 Likert-scale items with scores ranging from 17 to 68. Furthermore, each patient’s TSK score was used to categorize them as having a high degree of kinesiophobia (>37) or not (≤37). This cut-off score was selected as it has been previously used in populations with chronic lower extremity pain. Raw scores as well as proportions of patients with a high degree of kinesiophobia were used for analysis.

**Tendon Thickening**

Tendon thickening was quantified using ultrasound imaging. Ultrasound images were obtained using a LOGIQ e Ultrasound system (GE Healthcare, Chicago, IL, USA) with a wide-band linear array probe (5.0-13.0MHz). Thickness measurements were taken as described previously. Briefly, three extended field of view images were gathered bilaterally. Tendon thickness was measured 2 cm proximal to the calcaneal notch and at the thickest portion of the tendon (Figure 1). After averaging the three trials, tendon thickening was calculated as the difference (Tendon thickening = Thickness at the thickest portion – Thickness 2 cm proximal to insertion) and used for analysis. Tendon thickening, rather than typically reported raw value of tendon thickness, was used in this study as it controls for the baseline thickness of the tendon (i.e. thickness in the absence of pathology) and does not require a healthy, control side. Achilles tendinosis has been measured previously by comparing tendon thickness of a pathologic tendon to the thickness of a healthy side.

**Lower Leg Function**

Each patient’s jump performance and calf muscle endurance were measured using a countermovement jump (CMJ) and heel-rise endurance test, respectively. Both of these tests were performed as described in the literature and have been used for evaluating outcomes of patients with Achilles tendinopathy. All measures were obtained with a MuscleLab® measurement system (Ergotest Innovation, Porsgrunn, Norway). Functional testing procedures were not performed when patients reported a score of greater than five on the Numeric Pain Rating Scale during testing, demonstrated compromised balance, or had a diagnosed comorbidity that affected their ability to partake in strenuous exercise. This resulted in 14 subjects not performing the jumping task (four high activity; 10 low activity) and 5 not performing the heel-rise test (one high activity; four low activity).
Patients performed three single-leg CMJs alternating between legs as described previously.\textsuperscript{30} For each jump, patients were instructed to stand upright, place both hands behind their back, flex their knee as far as desired, and then immediately perform a single maximal vertical jump. Each CMJ was recorded using a field of infrared lights located approximately 4 mm above the ground, which allowed for calculation of jump height based on flight time (Height (m) = \( \frac{1}{2} \times \text{gravity} \times \text{time}^2 \)). The average jump height of the three trials for each leg was used for analysis.

A single-leg heel-rise endurance test was performed on each leg to measure calf muscle endurance as described previously.\textsuperscript{30} While standing on a 10° incline, with two fingers from each hand at shoulder height for balance, patients were instructed to perform as many heel-rises as possible while keeping their knee straight and maintaining a frequency of 30 repetitions/minute guided by a metronome. The test was terminated when the patient was unable to perform more repetitions or maintain the testing parameters. During the testing, a linear encoder was attached to the patient's heel in order to quantify the total work performed in joules, which was calculated with the following equation.

\[
\text{Work (J)} = \sum \text{displacement} \times \text{mass} \times \text{gravity}
\]

### Statistical Analysis

The outcome variables of interest included those related to demographic and injury characteristics, physical activity levels, symptom severity, kinesiophobia, tendon thickening, and lower leg function. Due to the data being non-normally distributed, statistical analyses were performed using nonparametric tests. Descriptive data are reported as median and interquartile range (IQR). Cohen's d effect sizes were calculated for each independent variable to improve interpretation of between group differences. All statistical analyses were performed using a significance level of p < 0.05. Sample sizes are reported for each outcome variable since patients were removed from individual analyses if they did not complete the test or questionnaire. The reason for missing questionnaire data (i.e. PAS, VISA-A, TSK, demographics) was because patients would skip questions and each data collection was completed before these outcomes were viewed or entered into data management software.

Mann-Whitney U tests were used to analyze differences between the high and low activity groups for demographic and injury characteristics and patient-reported outcomes (Adjusted VISA-A, TSK, PAS). Since 34 of the 53 patients presented with clinical signs of bilateral Achilles tendinopathy, each tendon was labeled as either the ‘more’ or ‘less’ symptomatic side based on patient reported symptoms and used for independent analyses of tendon thickening and lower leg function.\textsuperscript{30} Mann-Whitney U tests were used to analyze differences in tendon thickening and lower leg function between groups for both the more and less symptomatic sides. Additionally, a limb symmetry index (LSI (%) = more symptomatic/less symptomatic x 100) was calculated for the functional tests. LSI is a common metric reported in the literature\textsuperscript{30,32,33} and allows for group comparisons of side-to-side functional deficits. LSI values for CMJ and the heel-rise endurance test were analyzed with Mann-Whitney U tests. Wilcoxon Signed Rank tests were used to analyze changes in physical activity levels from before injury to the time of evaluation and to compare tendon thickening and functional tests between the more and less symptomatic side within each group. Pearson's Product-Moment Correlation was used to examine the relationship between tendon thickening and symptom severity. Fisher’s Exact tests were used to compare the proportions of patients with bilateral pathology in each group and to compare proportions of patients with high levels of kinesiophobia in each group.
a high degree of kinesiophobia when using scores greater than 37 on the TSK to operationally define a high degree of kinesiophobia.

**Tendon Thickening**

The low activity group had significantly greater tendon thickening than the high activity group on the more symptomatic side (p=0.037, d=0.616), but this was not seen on the less symptomatic side (p=0.128, d=0.466) (Table 5). Furthermore, the more symptomatic side had significantly greater tendon thickening than the less symptomatic side for both the low activity group (p<0.001, d=1.056) and the high activity group (p=0.002, d=0.656). When assessing the relationship between tendon thickening of the more symptomatic side and Overall VISA-A scores, there was a negative correlation (r=-0.49; p<0.001) (Figure 2).

### Table 2. Group Characteristics.

<table>
<thead>
<tr>
<th></th>
<th>High Activity Group (n=23)</th>
<th>Low Activity Group (n=30)</th>
<th>p-value</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>52 (34-60)</td>
<td>57 (44-65)</td>
<td>0.184</td>
<td>0.429</td>
</tr>
<tr>
<td>Sex (Male: Female)</td>
<td>17: 6</td>
<td>18: 12</td>
<td>0.384</td>
<td>0.351</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>180 (175-185)</td>
<td>178 (168-185)</td>
<td>0.560</td>
<td>0.207</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>78 (70-88)</td>
<td>91 (79-105)</td>
<td>0.031*</td>
<td>0.634</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24 (22-26)</td>
<td>28 (23-31)</td>
<td>0.007*</td>
<td>0.797</td>
</tr>
<tr>
<td>Duration of Symptoms (m)</td>
<td>8 (4-36) †</td>
<td>6 (3-14)</td>
<td>0.469</td>
<td>0.165</td>
</tr>
<tr>
<td>Unilateral: Bilateral</td>
<td>6: 17</td>
<td>13: 17</td>
<td>0.253</td>
<td>0.426</td>
</tr>
</tbody>
</table>

Data presented as Median (IQR) other than ‘Sex’ and ‘Unilateral: Bilateral’ which are presented as frequencies.

* Significant difference at the p<0.05 level † Sample size of 22

### Table 3. Physical Activity Levels.

<table>
<thead>
<tr>
<th></th>
<th>PAS Before Injury</th>
<th>PAS Currently</th>
<th>p-value</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Patients (n=53)</td>
<td>5 (4-6)</td>
<td>4 (3-6)</td>
<td>&lt;0.001*</td>
<td>0.508</td>
</tr>
<tr>
<td>Low Activity Group (n=30)</td>
<td>5 (4-5)</td>
<td>3 (3-4)</td>
<td>0.001*</td>
<td>0.917</td>
</tr>
<tr>
<td>High Activity Group (n=23)</td>
<td>6 (6-6)</td>
<td>6 (5-6)</td>
<td>0.102</td>
<td>0.404</td>
</tr>
</tbody>
</table>

Data presented as Median (IQR)
PAS= Physical Activity Scale
**= statistically significant difference at the p<0.01 level

### Table 4. Symptom Severity and the Degree of Kinesiophobia.

<table>
<thead>
<tr>
<th></th>
<th>Active Group (n=23)</th>
<th>Inactive Group (n=30)</th>
<th>p-value</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall VISA-A Scores</td>
<td>66 (56-79)</td>
<td>50 (37-70)*</td>
<td>0.007</td>
<td>0.868</td>
</tr>
<tr>
<td>Adjusted VISA-A Scores</td>
<td>48 (37-55)</td>
<td>39 (29-46)</td>
<td>0.078</td>
<td>0.491</td>
</tr>
<tr>
<td>TSK Scores</td>
<td>36 (32-40)</td>
<td>35 (33-40) †</td>
<td>0.969</td>
<td>0.027</td>
</tr>
<tr>
<td>Kinesiophobia (≤37: &gt;37)</td>
<td>14: 9</td>
<td>17: 10 †</td>
<td>0.999</td>
<td>0.049</td>
</tr>
</tbody>
</table>

Data presented as Median (IQR) other than ‘Kinesiophobia’ which is presented using frequencies

TSK= Tampa Scale of Kinesiophobia; VISA-A= Victorian Institute of Sport Assessment- Achilles questionnaire; Adjusted VISA-A= VISA-A score with questions 7 and 8 removed, (max score of 60)

* Sample size of 29 † Sample size of 27

Patient Reported Outcomes

For symptom severity, there was no significant difference (p=0.078, d=0.491) in adjusted VISA-A scores between the low and high activity groups (Table 4). For kinesiophobia, there were no significant differences in TSK scores (p=0.969, d=0.027) or proportions of patients with a high degree of kinesiophobia (p>0.999, d=0.049) between the low and high activity groups (Table 4). However, 38% (19 of 50 patients) of the entire cohort presented with d=0.508) lower than activity levels before injury. However, when analyzing each group individually, there was a significant reduction in physical activity for the low activity group (p=0.001, d=0.917) but not for the high activity group (p=0.102, d=0.404) (Table 3).
side-to-side differences in CMJ height for either the low activity (p=0.459, d=0.025) or high activity groups (p=0.117, d=0.217). Similarly, there were no significant differences (p=0.237-0.508, d=0.275-0.422) between the low activity and high activity groups for work performed on the heel-rise test.

**Functional Testing**

There were no significant differences (p=0.488-0.999, d=0.003-0.332) between the low activity and high activity groups for CMJ height on the more symptomatic side, less symptomatic side, or LSI (Table 5). Additionally, there were no significant side-to-side differences in CMJ height for either the low activity (p=0.459, d=0.025) or high activity groups (p=0.117, d=0.217). Similarly, there were no significant differences (p=0.237-0.508, d=0.275-0.422) between the low activity and high activity groups for work performed on the heel-rise test on the more symptomatic side, less symptomatic side, or LSI (Table 5).

### Table 5. Tendon Thickening and Lower Leg Function for Patients with High Activity (PAS≥5) and Low Activity (PAS<5).

<table>
<thead>
<tr>
<th></th>
<th>High Activity Group (n=23)</th>
<th>Low Activity Group (n=30)</th>
<th>p-value</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thickening</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More Symptomatic (mm)</td>
<td>1.3 (0.6-3.6)</td>
<td>3.6 (2.4-5.0)</td>
<td>0.037*</td>
<td>0.616</td>
</tr>
<tr>
<td>Less Symptomatic (mm)</td>
<td>0.8 (0.6-1.5)</td>
<td>1.5 (0.7-2.7)</td>
<td>0.128</td>
<td>0.466</td>
</tr>
<tr>
<td><strong>CMJ</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More Symptomatic (cm)</td>
<td>5.8 (4.8-8.8)</td>
<td>6.3 (4.2-9.1)</td>
<td>0.999</td>
<td>0.003</td>
</tr>
<tr>
<td>Less Symptomatic (cm)</td>
<td>6.4 (5.3-9.6)</td>
<td>6.2 (3.8-9.2)</td>
<td>0.488</td>
<td>0.127</td>
</tr>
<tr>
<td>LSI (%)</td>
<td>93 (79-110)</td>
<td>98 (79-110)</td>
<td>0.663</td>
<td>0.332</td>
</tr>
<tr>
<td><strong>Heel-Rise Work</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More Symptomatic (J)</td>
<td>1738 (1470-2074)**</td>
<td>1447 (298-2041)††</td>
<td>0.237</td>
<td>0.354</td>
</tr>
<tr>
<td>Less Symptomatic (J)</td>
<td>1868 (1410-2330)**</td>
<td>1662 (901-2378)††</td>
<td>0.508</td>
<td>0.275</td>
</tr>
<tr>
<td>LSI (%)</td>
<td>97 (81-104)**</td>
<td>88 (47-99)††</td>
<td>0.237</td>
<td>0.422</td>
</tr>
</tbody>
</table>

Structural and functional data are presented as Median (IQR).

PAS= Physical Activity Scale; CMJ= Countermovement Jump; LSI= Limb Symmetry Index; J= Joules

* p<0.05 † Sample size of 29 ‡ Sample size of 19 § Sample size of 20 ** Sample size of 22 †† Sample size of 26

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**Figure 2. Relationship of tendon thickening and overall VISA-A Score in patients with midportion Achilles tendinopathy. Physically active patients are represented as open circles while physically inactive patients are represented by closed circles.**
the more symptomatic side, less symptomatic side, or LSI (Table 5). However, the low activity group performed a significantly greater amount of work on the less symptomatic side compared to the more symptomatic side (p = 0.010, d = 0.291), but this was not observed in the high activity group (p = 0.072, d = 0.282).

DISCUSSION
The key finding of this study was that patients with Achilles tendinopathy who are below the recommended amount of physical activity (PAS < 5) did not have greater symptom severity, degree of kinesiophobia, or functional deficits compared to patients with high activity levels (PAS ≥ 5), rather, showed a greater amount of tendon thickening and higher BMI. Furthermore, tendon thickening was associated with self-reported symptom severity. Although the groups did not differ in regards to kinesiophobia, it is worth noting that 38% (19 of 50) of the patients demonstrated a high degree of kinesiophobia. Additionally, patients with low physical activity levels had significant reductions in their physical activity and a larger body mass compared to patients with high activity levels. Taken together, these findings led to rejecting the hypotheses that patients with low activity levels would have greater symptom severity, degrees of kinesiophobia, and no differences in tendon thickening or lower leg function compared to patients with high activity levels. This suggests that patients with Achilles tendinopathy who present clinically with low physical activity levels have a greater amount of tendon degeneration and greater body mass, but do not necessarily have worse symptoms or more fear of movement compared to their counterparts who have maintained high activity levels.

Symptom severity is not related to low activity levels
Quantifying clinical severity in patients with Achilles tendinopathy using the VISA-A is commonplace in research and recommended for evaluating patient-reported outcomes and response to treatment. It is often noticed that once a patient’s symptoms reach a certain level of severity, they reduce their physical activity and seek treatment. However, the existing evidence shows no detrimental effect of allowing continued physical activities during the rehabilitation process as long as a pain-monitoring model is followed. Results from the current study show that patients with midportion Achilles tendinopathy who are below the recommended amount of physical activity at the time of evaluation do not report worse symptoms compared to patients with high activity levels. This indicates that current symptoms do not explain the difference in clinical presentation between patients with different physical activity levels. However, patients often describe reductions in symptoms when decreasing their physical activity level. Therefore, despite no differences in symptom severity between these patients, it may be that the patients in the low activity group reduced their physical activity levels to minimize their symptoms.

Differences in Kinesiophobia
Current literature indicates that psychosocial variables, such as kinesiophobia, negatively impact clinical outcomes of patients with musculoskeletal pathologies. Although kinesiophobia has been mainly described in patients with low back pain, there is growing evidence that patients with lower
may simply follow a lengthier trajectory of recovery compared to symptoms. This notion is further supported by the finding that symptomatic recovery may not ensure functional recovery. The results from the current study show that greater amounts of tendon thickening occur in patients with low physical activity levels and to a greater extent on the more symptomatic side. This suggests that patients with low physical activity levels have greater structural changes. Additionally, a negative relationship (r = -0.49; p < 0.001) between tendon structure and symptom severity was found (Figure 2). Therefore, it appears that tendon structure may be a critical factor to monitor and address during the rehabilitation process to enable a safe return to physical activity participation. With training, clinicians can obtain valid and reliable measures of tendon structure that can be monitored over time with relatively low cost ultrasound systems.

Study Limitations

This study was not without limitations. This was the first study to compare patients with Achilles tendinopathy who have different physical activity levels and to use an adjusted VISA-A score as the primary outcome. Therefore, an a priori power analysis was not completed. The lack of between group differences in the adjusted VISA-A scores and functional outcome variables may represent Type II error. However, the group allocation ratio was determined to be representative of patients with midportion Achilles tendinopathy as it paralleled group allocation in a previous randomized controlled trial. A post-hoc sample size estimation was completed, which showed a sample size of 142 patients would have been needed to adequately power (power of 80%; α = 0.05) a comparison of symptom severity (adjusted VISA-A) between the groups.

Physical activity levels were patient-reported, which may introduce a source of error and bias. However, the PAS has been widely used in Achilles tendon research, it captures a wide array of physical activities and intensities, and the national recommendations for physical activity are based on self-report. There is also the possibility of recall bias when asking participants to report their activity levels prior to injury. Thus, changes in physical activity level should be viewed with caution.

The role of tendon structure

Achilles tendinosis, which is diagnosed using either diagnostic imaging or histologic samples, occurs when the collagen architecture has been altered, interfibrillar ground substance has increased, and vessels have infiltrated the tendon. Although tendinosis is characteristic of pathology and has been shown to predict future symptoms in asymptomatic tendons, there are mixed results on the association between tendon structure and symptoms. This has led many clinicians and researchers to call to question the utility of structural measures in the evaluation and management of tendinopathy. Growing evidence indicates that recovery of structure
There is currently no consensus for the cutoff score on the TSK that defines high levels of kinesiophobia. A cut-off score of >37 was used as it has been used in research of chronic lower extremity pathology. It is worth noting however that if a cut-off score of >35, which has also been used previously, was used, 56% (28 of 50) of our cohort would have presented with a high degree of kinesiophobia with still no differences between groups. Further longitudinal research is needed to determine the modifiable factors that can be used to predict positive clinical outcomes and safe return to physical activity.

CONCLUSION
Patient with Achilles tendinopathy with physical activity levels below the recommend 150 minutes per week at the time of evaluation have a higher BMI and greater amount of tendinosis and these structural changes are negatively related to symptom severity. These findings indicate that tendon structure is an important factor to consider at the time of clinical evaluation and potentially throughout the rehabilitation process. Furthermore, kinesiophobia might be a factor that influences the rehabilitation process in patients with Achilles tendinopathy, but it does not differ between patients who present with high and low physical activity levels. Similarly, symptom severity and lower leg functional deficits do not differ between patients with different activity levels, but nonetheless should be addressed during the rehabilitation process.

REFERENCES


ABSTRACT

Background: Femoroacetabular impingement can produce abnormal biomechanics that lead to compensatory injuries around the hip and pelvis. Ligamentum teres pathologies are commonly associated with these bony deformities but a mechanism for injury has not been described in the literature.

Purpose: The purpose of this study was to describe a potential mechanism behind ligamentum teres injury and impingement between the femoral neck and acetabulum.

Study Design: Laboratory controlled cadaveric study.

Methods: Twenty-six hips from 15 embalmed cadavers (8 male; 7 female) with lifespans between 55-93 years were skeletonized. The hip was placed in 90° flexion and 0° abduction/adduction and internally rotated until the femoral head neck contacted the acetabulum. This position of impingement with respect to internal rotation was recorded with a goniometer. The hip was then further internally rotated until end range of motion was achieved and again the position of internal rotation recorded with a goniometer.

Results: The positions of internal rotation at which impingement occurred (mean 9°; SD 4.2; Range -2° to 15°) when compared to end range (mean 21°; SD 5.7; Range 5° to 27°) were significantly different (p<0.005; t=14.8). In all the hips, after impingement occurred the site of bony contact between the femoral neck and acetabulum acted as a pivot point. The femoral head was levered inferiorly with a loss of the rotational center within the acetabulum, as internal rotation continued. This movement of the femoral head caused the ligamentum teres to tighten and restricted further movement. Movement into internal rotation beyond this end position caused rupture of the ligamentum teres.

Conclusion: Internal rotation range of motion can occur beyond the position of impingement and resulted in abnormal inferior movement of the femoral head and tightening of the ligament teres. This study provides cadaveric evidence for the mechanism of ligamentum teres injury in those with who engage in activities that required motion beyond the point of impingement.

Keywords: Femoroacetabular impingement, hip internal rotation, ligamentum teres, rotational stabilizer

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INTRODUCTION
Ligamentum teres (LT) pathology, in form of partial tears, are commonly seen in hip arthroscopy and can be associated with the bony deformities seen with developmental dysplasia and femoroacetabular impingement (FAI).\(^1\),\(^2\) Because the LT is described as a rotational hip stabilizer, instability occurring with dysplasia and the potential mechanism behind LT tears have been defined.\(^3\) Femoroacetabular impingement has been described as a dynamic disorder in which contact between the femoral neck and acetabulum produce abnormal biomechanics and damaging forces across the hip joint.\(^4\),\(^5\) These abnormal biomechanics may lead to compensatory injuries around the hip and pelvis, particularly in athletes.\(^6\) The mechanism behind LT pathology occurring with the abnormal biomechanics associated with impingement between the femoral neck and acetabulum has not been described.

Published reports on the prevalence of LT pathology in those undergoing hip arthroscopy have varied greatly, describing prevalence from 4% to 93%.\(^1\),\(^7\)\(^-\)\(^13\) Studies that include athletes with FAI reported some of the highest prevalence of LT pathology.\(^7\)\(^-\)\(^10\),\(^12\),\(^13\) The results of these studies support theories that the LT could be injured in sports that require positions that cause impingement between the femoral neck and acetabulum near end range of motion.\(^14\),\(^15\)\(^-\)\(^16\)\(^-\)\(^17\)\(^-\)\(^18\) The amount of internal rotation available at 90° of flexion was found to correlate with the amount of space between the femoral neck and acetabular rim.\(^19\) Once contact occurs, the acetabular rim is thought to induce a levering of the femoral head to cause posterior contra-coup lesions in the posterior wall of the acetabulum.\(^20\) The effect of this femoral head levering on the LT is unknown.

Once thought of as being only a vestigial structure, the purpose of the LT is becoming better understood.\(^3\) The function of the LT has been described using a ball and string model, with the LT acting as a sling, as it wraps around and pulls the femoral head into the acetabulum with rotational movements.\(^1\),\(^21\),\(^22\) This model is supported by studies that found the LT to add stability at the end range of hip motion in the frontal and transverse planes.\(^21\),\(^22\) In fact Martin et al\(^3\) found the LT to be the primary stabilizer of internal rotation when the hip was in 90° of flexion. Therefore, activities that require end range of internal rotation range in a position of hip flexion may contribute to LT injury, particularly if there are abnormal biomechanics occurring because of contact between the acetabular rim and femoral neck. The LT is a rotational stabilizer and tightens at the end range of internal rotation in flexion.\(^3\) Additionally, it known that LT injuries are common in FAI\(^7\)\(^-\)\(^10\),\(^12\),\(^13\) and that impingement between the femoral neck and acetabular rim occurs with hip flexion and internal rotation.\(^23\) The effect the abnormal biomechanics that occur with impingement has on the LT is unknown. The purpose of this study was to describe the potential mechanism behind LT tears and the abnormal biomechanics that occur after the femoral neck contacts the acetabulum.

METHODS
Twenty-six hips from 15 embalmed cadavers (8 male; 7 female) with a lifespan ranging between 55-93 years were included in this study. Each specimen was skeletonized and the hip capsule was vented with a square patch to allow full range of motion and visualization of the LT. The primary investigator positioned the hip in 90° of flexion and 0° of abduction/adduction using a bubble goniometer (Baseline® Bubble Inclinometer, Fabrication Enterprises Inc. White Plains, NY). The hip was then internally rotated until the femoral head neck junction contacted the acetabulum. This position of impingement with respect to internal rotation (IR) was recorded with a standard goniometer (Baseline® Goniometer, Fabrication Enterprises Inc. White Plains, NY) by the secondary investigator. The hip was then further internally rotated until end range of motion was achieved and again the position of IR was recorded with a standard goniometer. Each measure was repeated three times.

The version and inclination angles of the femur were measured by the secondary investigator using
a standard 12-inch goniometer (Baseline® Goniometer, Fabrication Enterprises Inc. White Plains, NY) and the version angles of the acetabulum were measured using a bubble goniometer (Baseline® Bubble Inclinometer, Fabrication Enterprises Inc. White Plains, NY) to describe the orientation of the acetabulum and proximal aspect of the femur. Acetabular version (AV) was determined by the angle formed by the sagittal plane and a line formed by connecting the midpoint of the anterior and the posterior acetabular rim. Femoral version (FV) was determined as the angle formed by a line bisecting the femoral head/neck and a line parallel to the posterior aspect of the femoral condyles. Femoral inclination (AI) was determined as the angle between a line bisecting the femoral neck relative to a line bisecting the femoral shaft. This study was approved by the ethics committee for anatomical studies of Duquesne University.

Statistical Analysis
All data was analyzed using a common statistical software system (SPSS Version 21, Chicago IL). The mean, standard deviation, and range of femoral and acetabular version and inclination angles were computed. A Paired T-test was performed to compare the amount of IR of the hip joint at the position of impingement and end range of motion. Reliability of the measurements were assessed with intra-class correlation coefficients (ICC 2,1) using the first and third measurement of internal of IR of the hip joint at the position of impingement and end range of motion.

RESULTS
The average AV, FV, and AI values are presented in Table 1 and were found to be 18° (SD 6; Range 9-31), 11° (SD 4; Range 3-20), and 37° (SD 6; Range 28-48). It was noted 12/14 cadavers had cam deformities with 17/26 having signs of bony reactive stress associated with FAI. These were determined by visual inspection of each femoral neck and head for abnormal bone growth and signs of osteoarthritic wear, respectively. No signs of irregular acetabular wear were noted beyond age-related changes to the cartilage.

Impingement occurred at a mean position of 9° IR (SD 4.2; Range -2° to 15°) while end range IR occurred at a mean position of mean position 21° IR (SD 5.7; Range 5° to 27°). The position of IR when impingement occurred compared to the position of end range IR were significantly different (p<0.005; t=14.8). In all 26 hips, after impingement occurred the site of bony contact between the femoral neck and acetabular rim acted as a pivot point, with the femoral head being levered inferiorly. Once this contact occurred (Figure 1), there was a loss of the rotational center within the acetabulum, as IR range of motion continued. This movement of the femoral head being levered inferiorly caused the LT to tighten, until the LT restricted further movement (Figure 2). Movement into IR beyond this end range of motion position caused rupturing of the LT in all hips. Measurements of IR when impingement occurred and position of end range IR were found to be reliable with ICC (2,1) values of 0.87 and 0.97, respectively.

DISCUSSION
This study provides cadaveric evidence for the mechanism of LT injury that occurs after the femoral neck contacts the acetabulum with hip internal rotation in flexion. Internal rotation range of motion can occur beyond the position of impingement, with a loss of the rotational center within the acetabulum, and inferior movement of the femoral head. This levering mechanism of the femoral head caused tightening and eventual rupture of the LT. These findings can be important in those who engage in athletics that require flexion and IR range of motion beyond the point of impingement, such as butterfly style goal tending.

Many sports have high range of motion demands that include forced hip internal rotation beyond end

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The results of this study indicate that internal rotation can occur after impingement but the rotation was associated with loss of rotation within the joint. Rotation range of motion beyond the impingement position caused the abnormal femoral head movement outside the acetabulum and tightening of the LT, as the LT attempted to hold the femoral head within the acetabulum. This forced rotation beyond end range of motion has been a proposed mechanism for focal rotational capsular hypermobility but may also be a mechanism for LT pathology. These findings may be particularly important in individuals engaged in activities requiring extreme range of motion, including hockey players and ballet dancers. The result of the current study supports a theory that the LT could be injured in an athlete when internal rotation occurs beyond end range of motion. The results also suggest a potential over-use injury, with repetitive levering the femoral head out of the acetabulum as a mechanism for LT injury.

This study is the first to describe a potential mechanism behind overuse partial LT tears in those who engage in activities that require repetitive extreme internal rotation in flexion. This overuse mechanism of injury would also correlate with findings that LT pathology in those with FAI that are usually partial tears and not complete ruptures. Additionally, a systematic review found evidence that LT injury can come from a non-traumatic overuse origin. In ballet dancers, injuries to the LT were postulated to occur as the LT attempts to maintain joint stability in movements that require extreme range of motion. An overuse mechanism was also supported by findings of only 29-34% with LT pathology reporting an acute mechanism of injury.
The role of LT pathology and symptom presentation remains an area of debate. Surgeons who perform open procedures and sacrifice the LT, question its importance as a hip stabilizer. Phillips et al.30 noted that only 24% of patients after surgical excision of the LT during open osteochondroplasty for cam deformities were found to be symptomatic with regard to instability. Martin et al3 found that subjects complained of instability only when osseous risk factors for instability and a complete LT tear were both present. While individuals with LT pathology may not complain of instability, they do complain of pain. Labral tears and cartilage damage are known to be pain generators, but pain may also be related to partial LT tears. Pain as a symptom in those with partial LT tears are well founded as free nerve endings were identified within the LT.27. Additionally, individuals who underwent arthroscopic LT debridement in the presence of an isolated LT tear commonly reported a decrease in pain.31,32

This biomechanical cadaveric study presents a number of limitations. An electronic tracking system could assist in positioning and measuring hip motion. All soft tissue superficial to the hip capsular ligaments was removed from the specimens. These structures offer stability to the hip joint and influence range of motion, particularly in an in vivo scenario with dynamic muscular action. The IR range of motion values obtained in this study were lower than normal values reported in the literature. However, given the age of the cadavers these values might not be that unusual. The results of the study were validated as those with the lower IR values at the position of impingement had bony findings that would be associated with these values, including decreased femoral version, decrease acetabular version, and fibrocystic lesions indicative of impingement. The effect of embalmed tissue on range of motion must also be considered. However, the capsule was vented to allow full free range of motion to prevent the capsule from restricting motion.

CONCLUSION
The results of the current study indicate that IR range of motion can occur beyond the position of impingement and resulted in abnormal inferior movement of the femoral head and tightening of the LT. End range of motion of hip IR at 90° of flexion and 0° of abduction/adduction was limited by the LT. This study provides cadaveric evidence for a mechanism of LT injury after the femoral neck contacts the acetabulum. This is of importance in those who engage in sports that require IR motion beyond the point of impingement.

REFERENCES


ABSTRACT

Background: Femoroacetabular impingement can produce abnormal biomechanics that lead to compensatory injuries around the hip and pelvis. Ligamentum teres pathologies are commonly associated with these bony deformities but a mechanism for injury has not been described in the literature.

Purpose: The purpose of this study was to describe a potential mechanism behind ligamentum teres injury and impingement between the femoral neck and acetabulum.

Study Design: Laboratory controlled cadaveric study.

Methods: Twenty-six hips from 15 embalmed cadavers (8 male; 7 female) with lifespans between 55-93 years were skeletonized. The hip was placed in 90° flexion and 0° abduction/adduction and internally rotated until the femoral head neck contacted the acetabulum. This position of impingement with respect to internal rotation was recorded with a goniometer. The hip was then further internally rotated until end range of motion was achieved and again the position of internal rotation recorded with a goniometer.

Results: The positions of internal rotation at which impingement occurred (mean 9°; SD 4.2; Range -2° to 15°) when compared to end range (mean 21°; SD 5.7; Range 5° to 27°) were significantly different (p<0.005; t=14.8). In all the hips, after impingement occurred the site of bony contact between the femoral neck and acetabulum acted as a pivot point. The femoral head was levered inferiorly with a loss of the rotational center within the acetabulum, as internal rotation continued. This movement of the femoral head caused the ligamentum teres to tighten and restricted further movement. Movement into internal rotation beyond this end position caused rupture of the ligamentum teres.

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Published reports on the prevalence of LT pathology in those undergoing hip arthroscopy have varied greatly, describing prevalence from 4% to 93%.\(^1\),\(^7\),\(^8\),\(^9\),\(^10\),\(^12\),\(^13\) Studies that include athletes with FAI reported some of the highest prevalence of LT pathology.\(^7\),\(^10\),\(^12\),\(^13\) The results of these studies support theories that the LT could be injured in sports that require positions that cause impingement between the femoral neck and acetabulum near end range of motion. In fact one study that included professional hockey players undergoing hip arthroscopy for FAI noted a 93% prevalence of LT pathology.\(^13\) End range of hip internal rotation range of motion is felt to be the primary source of impingement and has been documented to occur in athletes who participate in a number of sports, such as hockey,\(^14\),\(^15\) golf,\(^16\) ballet,\(^17\) and tae kwondo.\(^18\) The amount of internal rotation available at 90° of flexion was found to correlate with the amount of space between the femoral neck and acetabular rim.\(^19\) Once contact occurs, the acetabular rim is thought to induce a levering of the femoral head to cause posterior contra-coup lesions in the posterior wall of the acetabulum.\(^20\) The effect of this femoral head levering on the LT is unknown.

Once thought of as being only a vestigial structure, the purpose of the LT is becoming better understood. The function of the LT has been described using a ball and string model, with the LT acting as a sling, as it wraps around and pulls the femoral head into the acetabulum with rotational movements.\(^1\),\(^2\),\(^21\),\(^22\) This model is supported by studies that found the LT to add stability at the end range of hip motion in the frontal and transverse planes.\(^21\),\(^22\) In fact Martin et al\(^3\) found the LT to be the primary stabilizer of internal rotation when the hip was in 90° of flexion. Therefore, activities that require end range of internal rotation range in a position of hip flexion may contribute to LT injury, particularly if there are abnormal biomechanics occurring because of contact between the acetabular rim and femoral neck.

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This biomechanical cadaveric study presents a number of limitations. An electronic tracking system could assist in positioning and measuring hip motion. All soft tissue superficial to the hip capsular ligaments was removed from the specimens. These structures offer stability to the hip joint and influence range of motion, particularly in an in vivo scenario with dynamic muscular action. The IR range of motion values obtained in this study were lower than normal values reported in the literature. However, given the age of the cadavers these values might not be that unusual. The results of the study were validated as those with the lower IR values at the position of impingement had bony findings that would be associated with these values, including decreased femoral version, decrease acetabular version, and fibrocystic lesions indicative of impingement. The effect of embalmed tissue on range of motion must also be considered. However, the capsule was vented to allow full free range of motion to prevent the capsule from restricting motion.

CONCLUSION
The results of the current study indicate that IR range of motion can occur beyond the position of impingement and resulted in abnormal inferior movement of the femoral head and tightening of the LT. End range of motion of hip IR at 90° of flexion and 0° of abduction/adduction was limited by the LT. This study provides cadaveric evidence for a mechanism of LT injury after the femoral neck contacts the acetabulum. This is of importance in those who engage in sports that require IR motion beyond the point of impingement.

REFERENCES


ABSTRACT

Background: When paired together, manual therapy and exercise have been effective for regaining range of motion (ROM) in multiple conditions across varied populations. Although exercise in an aquatic environment is common, research investigating manual therapy in this environment is limited. There is little evidence on AquaStretch™ an aquatic manual therapy technique, but anecdotal clinical evidence suggests its effectiveness.

Purpose: To investigate the effects of AquaStretch™ on ROM and function in recreational athletes with self-reported lower extremity injury and pain.

Study Design: Quasi-experimental design.

Methods: Injured recreational athletes participated in a 30-minute intervention session of AquaStretch™. Injuries ranged from ankle (sprains and overuse), knee (contusions, sprains, and overuse), and hip conditions (contusions, overuse, and pain). Before a single intervention (preintervention) and within 24 hours after the intervention (postintervention), participants completed the following patient-reported outcome instruments: the Lower Extremity Functional Scale (LEFS) and the Foot and Ankle Ability Measure (FAAM) Sports subscale. AROM measurements of the ankle, knee, and hip and the following muscle length tests were measured: Ober's test, measurement of the popliteal angle, and the modified Thomas test. Finally, the overhead deep squat test was performed as a test of function.

Results: Twenty-six recreational athletes with lower extremity injuries of the ankle, knee, and hip, aged 18-60 years (18 males, 8 females, mean age 27.4 years) completed the study. The overall group by time interaction for the mixed-model Generalized Estimating Equations analysis was statistically significant for the LEFS ($p < .002$) and for the FAAM Sports subscale ($p < .01$). There were no statistically significant time (pre vs post) by group interactions for range of motion and other measures, including the Ober's test, the overhead deep squat test, popliteal angle, and the modified Thomas test for injured athletes.

Conclusion: One session of AquaStretch™ in recreational athletes improved the patient-rated outcome measures of function specifically the LEFS and FAAM Sports subscale. These results suggest that AquaStretch™ may be an effective form of manual therapy to improve lower extremity function in injured athletes.

Levels of Evidence: 2b, Individual Cohort Study

Key words: AquaStretch™, lower extremity, movement system
INTRODUCTION
Recreational exercise activities are common in the United States probably because of the health benefits associated with cardiovascular exercise.\(^1\),\(^2\) For those individuals who run for recreational exercise, lower extremity musculoskeletal injuries vary in frequency and type depending on the population studied, and prevalence rates range from 6.8 to 59 injuries per 1000 hours of running.\(^3\) In recreational runners, it is estimated that approximately half will sustain an injury in a given year.\(^4\) Musculoskeletal injuries are commonly related to overuse of the musculoskeletal system but are considered multifactorial.\(^3\) Most recreational runners experience musculoskeletal injuries in the lower extremities.

Interventions to address lower extremity musculoskeletal injuries in athletes vary and range from soft tissue mobilizations, modalities, pharmaceuticals, instrument-assisted mobilizations, such as instrument-assisted soft tissue mobilization or instrumented soft tissue mobilization, manual therapy techniques for the low back and lower extremity, and specific exercise approaches to address muscular imbalances.\(^5\)\(^-\)\(^13\) One of the most common interventions to address lower extremity injuries is soft tissue mobilization, which varies in both approach and technique when addressing these injuries. In a systematic review, Piper et al\(^14\) investigated the effectiveness of soft tissue mobilizations in the lower extremities compared with other interventions across the lifespan of individuals. The authors classified soft tissue mobilization as a mechanical form of therapy where soft tissue structures were passively pressed, kneaded, or stretched using physical contact with the hand or a mechanical device. They concluded that the effectiveness of most types of soft tissue therapy was not adequately investigated.\(^14\) For the lower extremity, soft tissue mobilization was effective for plantar heel pain, and trigger point approaches seemed to provide limited to no benefit.\(^14\) The authors found limited evidence for the effectiveness of soft tissue mobilization for other lower extremity injuries.\(^14\)

Clinically, soft tissue mobilizations may be combined with other manual therapy interventions such as active assisted movement of an extremity while applying physical pressure to a muscle to facilitate a muscular release. Some examples of manual therapy techniques and approaches include: soft tissue mobilization, joint mobilization, spinal manipulation, and manipulation of joints of the extremities. In addition, authors strongly suggest that manual therapy techniques be combined with exercise to be most effective.\(^15\)\(^-\)\(^18\) Thus, for lower extremity injuries, manual therapy combined with exercise is effective in decreasing pain and improving function.\(^15\)\(^-\)\(^18\) As such, specific exercise combined with manual therapy is often used to address muscle imbalances in the lower extremity. For example, interventions to address patellofemoral pain syndrome, a common condition in female runners, involves strengthening the hip.\(^19\)\(^-\)\(^21\) However, there are several classifications of patellofemoral pain syndrome and it is unknown what specific exercises are best matched with specific classifications of this diagnosis. It is clear to the clinician that more evidence is needed to investigate specific exercises in combination with manual therapy techniques to determine appropriate approaches that are most useful for treating lower extremity conditions.

AquaStretch™ is a technique that combines manual therapy and active assisted exercise in a gravity-reduced aquatic environment. This intervention has been reproduced in clinical settings and has shown improvement in range of motion (ROM) after a single treatment session in non-injured individuals.\(^22\) AquaStretch™ has anecdotal clinical evidence but limited research evidence to show its usefulness to restore ROM and function. The purpose of the current study was to investigate the effects of AquaStretch™ on ROM and function in recreational athletes with self-reported lower extremity injury and pain. The hypothesis that AquaStretch™ would improve ROM and function in recreational athletes was tested.

METHODS
Adult, recreational athletes with self-reported lower extremity injury were recruited for the current study from a health sciences university using flyers and convenience sampling. Potential participants had to be aged 18-60 years and currently training for at least seven hours per week for sport or exercise or be involved in intense physical training for at least four hours a week. They also had to have a
current lower extremity injury or pain in the prior 6 months and a deficit in any active lower extremity ROM values on the injured side compared with the contralateral extremity. In the current study, injury was defined as any physical dysfunction that limited a person’s participation in physical activity, and training was defined as activities related to any exercise directed toward improving function for sport (eg, running, cycling, sprinting). Intense physical training was considered high impact or plyometric movement that involved power and explosive movements, such as CrossFit. Exclusion criteria included surgery in the prior six months; a ligament, tendon, or meniscus tear in the prior six months, or general aquatic therapy precautions and contraindications. Specifically, AquaStretch™ precautions and contraindications include the following: fractures, muscle tears, joint laxity, postoperative considerations, joint replacements, osteoporosis, anticoagulant medications (possible bruising), long-term steroid usage, edema of unknown cause (medical clearance recommended), active cancer, current or past radiation, heavy medications or substance abuse, litigation cases, non-responsive first treatment (ie, hydrophobic), active infection, cauda equina symptoms, ankylosing spondylitis, and aortic aneurysm. Demographic information about the participants was collected and included age, sex, and type of recreational activity participation. The local institutional review board approved the current study, and all participants signed an approved informed consent form prior to participation. No adverse events occurred during this study.

**Outcome Measures**

Prior to the AquaStretch™ intervention (preintervention) and within 24 hours after the intervention (postintervention), participants completed the following patient-reported outcome (PRO) instruments: the Lower Extremity Functional Scale (LEFS) and the Foot and Ankle Ability Measure (FAAM) Sports subscale. The preintervention PRO instruments were completed when the participant arrived at the facility and were included as part of the required study paperwork. Additionally, AROM measurement tests of the ankle, knee, and hip were performed and measured with a goniometer. Additional measures commonly used in physical therapy practice were performed and measured with a digital inclinometer on the IPhone iOS7 and the Hudl Technique application (IPhone application) to include: Ober’s test, measurement of the popliteal angle, and the modified Thomas test, and the overhead deep squat test. Preintervention ROM measurements were performed immediately prior to the AquaStretch™ intervention. Postintervention measurements, including PRO instruments, were completed immediately after the intervention to limit outside factors that could influence the effects of the intervention. Even though the FAAM requires the participant to recall effects from the past week, the investigators still included it as part of the postintervention measurements because the investigators wanted to investigate the effect of the participant’s injury on their daily activities before the intervention.

The preintervention and postintervention test measurements were performed by two third-year physical therapy students trained in performing the test measures. To improve accuracy, the student physical therapists conducted repeated tests for all measures on volunteers and during their clinical rotations prior to performing the tests on research participants in the current study. Preintervention and postintervention measurements were performed by the same tester for each measure for each participant.

**Ankle, Knee, and Hip ROM Measurements**—A single ROM measurement was taken for all available ROM actions and was measured bilaterally using a standard 12-inch goniometer for the hip and knee joints and a 6-inch protractor goniometer for the ankle joint (Prestige Medical, Northridge, CA). These goniometers were used throughout the study, and measurements were performed from proximal to distal to avoid the participant moving around too much. Ankle ROM measurements included dorsiflexion, plantarflexion, inversion, and eversion. Knee ROM measurements included flexion and extension. Hip ROM measurements included flexion, extension, internal rotation, external rotation, abduction, and adduction. The following positions were used for the ROM and other measurements: participants were in supine for ankle dorsiflexion, ankle plantarflexion, knee flexion, knee extension, hip flexion, hip abduction, hip adduction, the modified Thomas test, and the popliteal angle test. Participants were
in long sitting for ankle inversion and ankle eversion; participants were in short sitting at the edge of a plinth for hip external rotation and hip internal rotation; participants were in side-lying for the Ober's test; and participants were in prone for the hip extension ROM measurement. Landmarks for all lower extremity ROM measurements were standardized. The following landmarks were used:

- **Hip flexion**: axis at the greater trochanter, moving the arm directed at the lateral epicondyle of the femur and stabilizing the arm directed at the midline of the torso.
- **Hip extension**: axis at the great trochanter, moving the arm at the lateral epicondyle and stabilizing the arm directed at the midline of the torso. Hip extension is performed with a bent knee.
- **Hip abduction**: axis at the same side ASIS, moving the arm bisecting the quadriceps directed at the patella and stabilizing the arm directed at the opposite ASIS.
- **Hip adduction**: axis at the same side ASIS, moving the arm bisecting the quadriceps directed at the patella and stabilizing the arm directed at the opposite ASIS.
- **Hip internal rotation**: axis at the midpoint of the patella, moving the arm at midway between the lateral/medial malleoli and stabilizing the arm directed perpendicular to the floor.
- **Hip external rotation**: axis at the midpoint of the patella, moving the arm at midway between the lateral/medial malleoli and stabilizing the arm directed perpendicular to the floor.
- **Knee flexion**: axis at the lateral epicondyle of the femur, moving the arm directed at the lateral midline of the fibula, referencing the lateral malleolus/fibular head, and stabilizing the arm directed toward midline of the femur, referencing the greater trochanter.
- **Knee extension**: axis at the lateral epicondyle of the femur, moving the arm directed at the lateral midline of fibula, referencing the lateral malleolus/fibular head, and stabilizing the arm directed toward midline of the femur, referencing the greater trochanter.
- **Ankle dorsiflexion**: axis at the lateral malleolus, moving the arm directed to the lateral aspect of the 5th metatarsal and stabilizing the arm directed toward the lateral midline of the fibula, referencing the fibular head.
- **Ankle plantarflexion**: axis at the lateral malleolus, moving the arm directed to the lateral aspect of the 5th metatarsal and stabilizing the arm directed toward the lateral midline of the fibula, referencing the fibular head.
- **Ankle inversion**: axis over the anterior aspect of the ankle between the malleoli, moving the arm directed toward the anterior midline of the 2nd metatarsal and stabilizing the arm directed toward the midline of the lower leg, referencing the tibial tuberosity.
- **Ankle eversion**: axis over the anterior aspect of the ankle between the malleoli, moving the arm directed toward the anterior midline of the 2nd metatarsal and stabilizing the arm directed toward the midline of the lower leg, referencing the tibial tuberosity.

**Ober's test**—Ober's test was used to measure the flexibility of the iliotibial band in the current study. The Ober's test has excellent intrarater reliability (intraclass correlation coefficient [ICC] = 0.90). Standard procedures were followed for the Ober's test as described by Reese and Bandy. The participant was positioned on an examination table in side-lying with the hip and knee of the left lower extremity flexed to 45° and 90°. The tester stabilized the participant's pelvis with one hand and placed the other hand under the participant's thigh just above the knee to support the leg. The tester then passively abducted and extended the hip in line with the trunk. The tester asked the participant to relax while allowing the uppermost limb to drop toward the table through the available hip adduction ROM. The end point of hip adduction was defined as the point at which lateral tilting of the pelvis was palpated, when the hip adduction movement stopped, or both. At the end point of hip adduction, the tester maintained the alignment to ensure no pelvic tilting or internal rotation and flexion of the hip occurred. An iPhone smartphone with an iOS7 (Apple Inc., China) digital level inclinometer app was placed over
the mid-thigh. If the leg was below horizontal, the measurement was recorded as a negative number; if it was above horizontal, it was recorded as a positive number. End range of motion was determined to be the onset of tightness with overpressure to the onset of discomfort. We used the smartphone app because it was convenient, and authors suggest good reliability. Vohralik et al. demonstrated excellent interrater and intrarater reliability when comparing the use of smartphone apps to the inclinometer when measuring ROM. In a systematic review, Milani et al. investigated the reliability of smartphone apps for determining ROM in static position of the lower extremity (hip, knee flexion, and ankle dorsiflexion) and found good to excellent intraobserver (ICC range, 0.80-0.96) and interobserver (ICC range, 0.80-0.99) reliability.

**Popliteal Angle Test.**—The popliteal angle was measured as described by Winslow et al. The popliteal angle was measured on both sides, but measurement of the right popliteal angle is described here. The participant was positioned in supine on an examination table with the tester stabilizing the anterior superior iliac spines and mid-thigh of the left lower extremity. The participant was asked to bring the right thigh towards the chest, supporting it with both hands clasped behind the knee. The tester placed the participant's anterior thigh perpendicular to the table. The participant was then asked to actively straighten the lower leg. Using a goniometer, the popliteal angle measurement was taken at the end of the range of active knee extension, which is the degree of knee flexion from terminal knee extension.

**Modified Thomas Test.**—The modified Thomas test was measured as described by Kendall et al. and was used to determine lower extremity flexibility for the iliopsoas and quadriceps musculature. The modified Thomas test is commonly used in the clinic and has moderate intrarater reliability (ICC = 0.51). Testing was done bilaterally, but measurement of the left lower extremity is described here. The participant sat with the gluteal fold positioned at the end of the examination table. The tester placed one hand behind the participant's back and the other hand under the right knee, flexing the thigh toward the chest and assisting the participant into supine position. The participant then stabilized the right thigh against the chest to limit lumbar spine motion. The participant was then instructed to relax the left lower extremity, allowing the hip to extend and the knee to flex over the edge of the table. Hip range of motion was measured parallel to the femur compared with the trunk, and knee range of motion was measured parallel to the fibula compared with the femur with use of a goniometer.

**Overhead Deep Squat Test.**—The Functional Movement Screen™ (FMS) overhead deep squat test was used in the current study to analyze shoulder, hip, knee, and ankle ROM measures. Following the FMS protocol, participants of the current study held a dowel overhead during the movement. Cuchna et al. state that using the dowel improved test reliability and scoring and makes the testing more functional. The FMS overhead deep squat test starts with the participant standing and placing the feet approximately shoulder width apart with the feet aligned in the sagittal plane. The participant places the dowel on the head and adjusts hand placement to 90° elbow flexion. Next, the dowel was pressed overhead with the elbows fully extended. The participant was then instructed to descend into as deep a squat position as possible. If required, verbal cues were given by the tester so that the participant kept the heels on the floor and pressed the dowel maximally overhead. The participant was allowed to repeat the movement up to 3 times. For consistency, the participant's squat was recorded 92.5 inches away with the smartphone Hudl Technique app from the left sagittal view. The video was stopped at the deepest squat position, which was determined visually; and shoulder, hip, knee, and ankle ROM were measured using features of the smartphone app. Shoulder ROM was measured to determine how the trunk of the participant influenced motion.

**Lower Extremity Functional Scale (LEFS)—**The LEFS consists of 20 questions that evaluate lower extremity functional activities and has a possible score of 80 points. Higher scores on the LEFS indicate a better level of function. The LEFS has excellent test-retest reliability (ICC = 0.88) and validity as well as responsiveness to change in patients with lower extremity disorders. The minimal clinically important difference (MCID) of the LEFS is 9 points,
and this difference reflects a clinically important functional gain.30

**Foot and Ankle Activity Measure (FAAM) Sports Subscale**—The FAAM sports subscale is a region-specific, self-report questionnaire with 21 Likert-like response questions, which range from 0 (unable to do the activity) to 4 (no difficulty). Scores are added together and multiplied by 4 for scoring. The FAAM Sports subscale has excellent test-retest reliability (ICC = 0.87) and validity.30 The MCID is 9 percentage points on a 0%-100% scale, and this difference reflects a clinically important improvement in activities.30

**AquaStretch™ Intervention**
The AquaStretch™ intervention was performed by a certified AquaStretch™ clinician. The AquaStretch™ clinician providing the intervention in the current study was a third-year physical therapy student who was interested in AquaStretch™ and had learned it outside of the course curriculum. The clinician had been using AquaStretch™ in a recreational manner for over a year before the current study was initiated. The clinician learned and practiced AquaStretch™ under the supervision of the developer of the technique and a physical therapist who had been using AquaStretch™ as an intervention since 2010. The AquaStretch™ clinician who performed the intervention in the current study received certification prior to initiation of the study. Certification involved performing the intervention on 50 healthy participants under the direction of a certified AquaStretch™ instructor and receiving 25 hours of training. The AquaStretch™ intervention was performed following the approach by Eversaul et al.23 The intervention was performed in a chlorinated pool that ranged from 3.5 feet to 6 feet in depth. Participants in the current study were treated at the 3.5 foot depth. The average temperature of the pool was 33°C.

Each AquaStretch™ session was 30 minutes. Specific protocol positions were used to focus the AquaStretch™ intervention on the lower extremity addressing all available bilateral joints (ankle, knee, and hip). The positions used in the study were the following:

- Wall hang positions: foot grip, ankle grip, toe grip, iliotibial band pump, hip rock, and hip roll (Figures 1-5 for positions)
- One-leg standing with fulcrum performed bilaterally (Figure 6)
- Two heavy feet positions: lean back, arch forward, assume the position, back against the wall, and shoulder roll (Figures 7-10 not pictured: shoulder roll)
- Head hang (Figure 11)

For every position, except for the wall hang, 5- to 15-lb weights were used to adjust resistance and maintain foot contact with the bottom of the pool. The ankle weights were applied to one or both ankles just superior to the malleoli. The clinician was directly in front of the participant for wall hang positions, iliotibial band pump, hip rock, and hip roll; lateral to the participant for one-leg standing; behind the participant for two heavy feet; and directly lateral of the participant for head hang. The clinician adjusted the resistance weights based on participant size and presentation. All participants performed all protocol positions bilaterally during the 30-minute session.
After entering the pool and before beginning the four-step AquaStretch™ basic procedure, the participant was instructed to immediately say stop or less if they experienced any discomfort or pain. The AquaStretch™ clinician encouraged movement during treatment by telling the participant to “move if you feel the need to move” while the clinician applied manual pressure. Manual pressure was applied to the area the participant felt pain and gradually increased until a stretch reflex movement was elicited. The gradual increase in pressure was performed after the clinician had determined the voluntary movement of the participant. The increase in pressure assisted the participants by allowing them to go into bigger ranges of movement not attainable by themselves. For example, during the foot grip, the stretch was directed in the movement of plantarflexion and inversion (Figure 1 and 2). Participants were allowed to move if they needed to. The pressure applied in those directions was increased until the participant’s extremity began to move freely in the water. The clinician could then direct the movements in different ranges to better facilitate the stretch and increase the amount of pressure needed to achieve
felt. The clinician carefully observed the movement of the extremity from above the water just prior to this freezing to determine the vector to continue assisted stretching. Third, the clinician placed manual pressure where the participant felt pain or restriction. Pressure was added while the participant maintained the position so that tension was held in the extremity. Fourth, the participant’s stretch reflex was engaged by increasing pressure until movement was elicited, while indicating the participant should move if inclined. The participant was encouraged to move the entire body as the clinician continued pressure, accenting the movement, until greater ranges of movement were achieved.

**Statistical Methods**

Tests for normality were run for all outcomes through visual analysis of histogram and Q-Q plots. Since normality was achieved, mixed model generalized estimating equations (GEE) analyses were used. The \( p \) values of the \( \beta \) coefficients were analyzed by 2-tailed Wald tests to compare preintervention and postintervention outcomes for the primary patient-rated outcome measures of the LEFS and FAAM Sports subscale as well as for lower extremity ROM measurements and for the additional measures, eg, the Ober’s test, popliteal angle, the modified Thomas test, and overhead deep squat. An \( \alpha \) of .05, 2-tailed, was set a priori for the current study, 95% confidence intervals, and effect size were reported as appropriate. SPSS version 24.0 (IBM, Armonk, New York) was used for the analyses.

**Figure 5.** Wall Hang, Hip rock and roll. Superior view: clinician hand grasps superior aspect of iliac crests.

A release. The participant’s reflexive movement was then directed by the clinician into end range. If necessary, the participant was asked to “move with me,” and the clinician directed the movement.

Before moving onto different positions, the clinician directed the participant through specific stages of movement as termed by AquaStretch™ “play, freeze, pressure, and move” sequencing. First, the participant was asked to play with the body’s movement and find any position where pain, discomfort, restrictions, or asymmetries were experienced between the lower extremities. Second, the participant was asked to freeze the body in the position where pain or restriction was

**Figure 6.** One Leg Standing with Traction. a. clinician provides anterior hand pressure to posterior aspect of sacrum (advanced facilitation of hip joint). b. Full view: clinician performs foot grip (1b) with traction applied while participant is holding onto a stable surface.
Figure 7. Two Heavy Feet, Lean back. a. Full view: clinician provides bilateral hand support of participant neck close to the occiput while participant leans back. b. Full view: same interpretation as 7a; except done on land.

Figure 8. Two Heavy Feet: Arch forward. Full view: clinician provides bilateral hand support of participant neck close to the occiput while participant arches forward.

Figure 9. Two Heavy Feet, Assume the Position (Cops). a. Lateral view: clinician hands on upper rim of ilium with thumbs on SI joint / paraspinals. b. Posterolateral view: same interpretation as 9a.
RESULTS

Twenty-six recreational athletes (18 males, 8 females) aged 18-60 years (mean age, 27.4 years) with varied self-reported lower extremity injuries participated in the study. All participants in the current study had existing lower extremity injuries of the hip, knee or ankle with specific demographic characteristics of study participants presented in Table 1.

Statistically significant differences were found between preintervention and postintervention outcomes for 11 of the 24 ROM measurements on the uninjured limb of the athletes (Table 2). However, none of the measurements at the ankle, knee, and hip were significantly different pre- to postintervention for injured athletes.

Figure 10. Two Heavy Feet, Back against the wall. a. Lateral view: clinician provides bilateral hand support of neck close to occiput with knee placement toward mid-scapula. b. Lateral view (close up): same interpretation as 10a with adaptation of hand placement for better control.

Figure 11. Head Hang. 11a. Lateral view: clinician posterior hand at base of skull and anterior hand supporting chin. 11b. Lateral view: participant kneels in water while clinician supports.

Table 1. Demographic Characteristics of the Recreational Athletes (N = 26) of the Current Study.

<table>
<thead>
<tr>
<th>Demographic Characteristic</th>
<th>No. (%) or Mean (SD)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>18 (69)</td>
</tr>
<tr>
<td>Female</td>
<td>8 (31)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>27.4 (1.0)</td>
</tr>
<tr>
<td>Sports</td>
<td></td>
</tr>
<tr>
<td>Runners</td>
<td>25 (96%)</td>
</tr>
<tr>
<td>Triathletes</td>
<td>7 (27%)</td>
</tr>
<tr>
<td>Marathoners</td>
<td>4 (15%)</td>
</tr>
<tr>
<td>Mixed martial arts</td>
<td>2 (.07%)</td>
</tr>
<tr>
<td>Region of injury</td>
<td></td>
</tr>
<tr>
<td>Hip</td>
<td>9 (35%)</td>
</tr>
<tr>
<td>Knee</td>
<td>9 (35%)</td>
</tr>
<tr>
<td>Ankle/foot</td>
<td>8 (30%)</td>
</tr>
</tbody>
</table>

* Age is reported as mean (SD).
Table 2. Preintervention and Postintervention Measurements for Range of Motion in Recreational Athletes of the Current Study (N = 26). No injury indicates the uninjured limb, while injury indicates the injured limb. Subjects served as their own controls.

<table>
<thead>
<tr>
<th>ROM, degrees</th>
<th>Preintervention in degrees, Mean (SD)</th>
<th>95% CI</th>
<th>Postintervention in degrees, Mean (SD)</th>
<th>95% CI</th>
<th>p Value</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ankle dorsiflexion (no injury)</td>
<td>7.09 (4.19)</td>
<td>5.31 to 8.87</td>
<td>11.27 (5.22)</td>
<td>&lt;.001*</td>
<td>.88</td>
<td></td>
</tr>
<tr>
<td>Ankle dorsiflexion (injury)</td>
<td>5.31 (5.11)</td>
<td>4.26 to 6.36</td>
<td>6.76 (4.13)</td>
<td>.15</td>
<td>.35</td>
<td></td>
</tr>
<tr>
<td>Ankle plantarflexion (no injury)</td>
<td>54.92 (9.67)</td>
<td>45.02 to 64.87</td>
<td>58.69 (6.84)</td>
<td>.002*</td>
<td>.46</td>
<td></td>
</tr>
<tr>
<td>Ankle plantarflexion (injury)</td>
<td>51.02 (5.83)</td>
<td>47.50 to 54.54</td>
<td>55.93 to 61.45</td>
<td>.02</td>
<td>.29</td>
<td></td>
</tr>
<tr>
<td>Ankle inversion (no injury)</td>
<td>34.12 (6.60)</td>
<td>30.10 to 38.14</td>
<td>36.57 (7.19)</td>
<td>.01*</td>
<td>.35</td>
<td></td>
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<tr>
<td>Ankle inversion (injury)</td>
<td>30.01 (7.69)</td>
<td>26.90 to 33.12</td>
<td>32.86 to 40.70</td>
<td>.01</td>
<td>.35</td>
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<tr>
<td>Ankle eversion (no injury)</td>
<td>11.27 (5.77)</td>
<td>9.63 to 12.91</td>
<td>13.65 to 17.56</td>
<td>.01</td>
<td>.35</td>
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<tr>
<td>Ankle eversion (injury)</td>
<td>9.39 to 13.36</td>
<td>8.67 to 14.08</td>
<td>10.02 to 13.51</td>
<td>.01</td>
<td>.35</td>
<td></td>
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<tr>
<td>Knee flexion (no injury)</td>
<td>144.86 (7.21)</td>
<td>140.63 to 149.04</td>
<td>148.29 (8.55)</td>
<td>&lt;.001*</td>
<td>.43</td>
<td></td>
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<tr>
<td>Knee flexion (injury)</td>
<td>141.56 to 148.24</td>
<td>137.33 to 152.47</td>
<td>144.29 to 152.40</td>
<td>.01</td>
<td>.35</td>
<td></td>
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<tr>
<td>Knee extension (no injury)</td>
<td>141.33 (7.39)</td>
<td>137.10 to 145.56</td>
<td>145.87 (8.08)</td>
<td>.01</td>
<td>.35</td>
<td></td>
</tr>
<tr>
<td>Knee extension (injury)</td>
<td>140.63 to 145.68</td>
<td>136.40 to 150.31</td>
<td>143.07 to 148.73</td>
<td>.01</td>
<td>.35</td>
<td></td>
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<tr>
<td>Hip flexion (no injury)</td>
<td>121.84 (7.88)</td>
<td>118.62 to 125.06</td>
<td>125.42 (9.41)</td>
<td>&lt;.001*</td>
<td>.41</td>
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<tr>
<td>Hip flexion (injury)</td>
<td>118.46 to 125.33</td>
<td>115.23 to 128.56</td>
<td>121.95 to 128.99</td>
<td>.01</td>
<td>.35</td>
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<tr>
<td>Hip extension (no injury)</td>
<td>120.89 (11.77)</td>
<td>117.66 to 124.12</td>
<td>125.381 (9.54)</td>
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<td>.35</td>
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<tr>
<td>Hip extension (injury)</td>
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<td>114.04 to 127.88</td>
<td>122.40 to 128.43</td>
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<td>.35</td>
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<tr>
<td>Hip internal rotation (no injury)</td>
<td>34.94 (6.43)</td>
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<td>35.88 (6.91)</td>
<td>.001*</td>
<td>.54</td>
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<td>Hip internal rotation (injury)</td>
<td>33.96 to 39.85</td>
<td>30.70 to 43.12</td>
<td>35.99 to 41.35</td>
<td>.001*</td>
<td>.54</td>
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<td>Hip external rotation (no injury)</td>
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<td>33.25 to 40.35</td>
<td>36.51 to 43.12</td>
<td>.001*</td>
<td>.54</td>
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<td>28.09 (7.81)</td>
<td>25.57 to 30.87</td>
<td>30.95 to 36.36</td>
<td>.001*</td>
<td>.54</td>
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<tr>
<td>Hip adduction (no injury)</td>
<td>14.37 (4.79)</td>
<td>12.31 to 16.85</td>
<td>17.21 (5.09)</td>
<td>&lt;.001*</td>
<td>.57</td>
<td></td>
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<tr>
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<td>13.43 (4.44)</td>
<td>11.81 to 15.27</td>
<td>15.97 (5.45)</td>
<td>.01</td>
<td>.35</td>
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<td>35.56 to 42.90</td>
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<td>.01</td>
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<tr>
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<td>36.15 to 46.16</td>
<td>41.85 (6.29)</td>
<td>.01</td>
<td>.35</td>
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* Denotes a statistically significant difference.

Abbreviations: CI, confidence interval; SD, standard deviation.

(Table 2). Statistically significant differences were found between preintervention and postintervention outcomes for three of the eight special tests or muscle length measurements on the uninjured limb of the athletes (Table 3). However, the special tests or muscle length measurements of ankle, knee, and hip were also not significantly different pre- to postintervention for injured athletes (Table 3). The functional measures for uninjured athletes were statistically significantly different for the FMS™ deep squat knee, the LEFS, and the FAAM (Table 4). Cohen's definition of effect size was used; effect size of 0.2 was considered a small effect size, 0.5 was considered a moderate effect size, and 0.8 was considered a large effect size.36 Effect sizes...
30 minutes of AquaStretch™ for the LEFS and the FAAM Sports subscale but the differences were not clinically significant as they did not reach the MCID for both self-reported functional outcome measures.

In the current study, the investigators measured bilateral lower extremity differences in ROM and additional measures commonly used in physical therapy practice because research suggests bilateral differences are found in recreational athletes. The reader should note those measures that are statistically different (*asterisk) and also note the effect size to determine the magnitude of the difference between the measures.

**DISCUSSION**

Recreational athletes showed statistically significant differences preintervention to postintervention after varied between the ROM and additional measures and are reported in Tables 2, 3, and 4. The reader should note those measures that are statistically different (*asterisk) and also note the effect size to determine the magnitude of the difference between the measures.
and may influence risk factors for lower extremity injury. The additional measures used were selected to identify muscle flexibility. Statistically significant differences were found for the uninjured limb of the athletes for the Ober’s test, the popliteal angle test, and for the overhead deep squat hip measurements. The effect sizes for the ROM and additional measures varied from small to large across all measures. Effect size is the magnitude of the differences between measures and is not dependent on the sample size. To determine statistical significance, both the p value and the effect size should be evaluated. Authors found that the Ober’s test (n = 28) and modified Ober’s test (n = 34) do not just measure or determine iliotibial band tightness and seem to assess tightness in structures located proximally to the coxofemoral joint. For the current study, the results of the Ober’s test may suggest that AquaStretch™ improved the flexibility of more than lower extremities but only for the uninjured limb of the athletes. This was a surprising finding as the expectation was that the athletes would improve on the injured limb based on previous literature suggesting lower extremity goniometric measurement improvements after one 30-minute session of AquaStretch™ intervention. The authors suggest that it may take more than one session to create significant soft tissue changes in muscle in order to improve the extensibility of the muscle tissues and demonstrate change in muscle length testing.

No statistically significant differences were found for the modified Thomas knee measure, but differences were found for the overhead deep squat test as measured at the hip, knee, and ankle albeit with small effect sizes. This functional gain was also found for the LEFS but the MCID of 9 points was not reached indicating this gain may not be due to the intervention. The MCID was also not obtained for the FAAM Sports subscale. Perhaps this was due to the AquaStretch™ intervention being performed only once for 30 minutes. Another possibility is that the participant continued to compensate for the injured limb but was still able to perform without a movement limitation. Additionally, the significant findings of improvement in movement on the uninjured limb could be because the athlete over-compensated for the injured limb; thus, leading to antalgic motor patterns reflected in AROM measurements. Future studies should evaluate the appropriate intervention dosage needed to obtain both statistically significant and clinically significant differences.

The mechanism for AquaStretch™ has not been established. The AquaStretch™ intervention is purported to be a soft tissue technique that breaks up fascial adhesions, and the manual therapy techniques are similar to those a manual therapist would perform on a patient in clinical setting for common treatments on musculoskeletal conditions. Manual therapy is thought to influence afferent nociceptors, which reduces the pain perceived by the patient, improves the sensorimotor mismatches, and potentially actuates antinociceptive pathways thereby decreasing spinal hyperexcitability. This may result in an improved motor pattern of movement potentially with a return to normal movement. The effects on the patient that are found after manual therapy is performed may also be true for AquaStretch™ but more research is needed to determine if these effects occur after this technique is implemented. The mechanism of this intervention allows the clinician to address each joint in a multi-planar motion. The methodology behind AquaStretch™ suggests that the ability to address each joint in all planes of movement at once allows the clinician to address fascial adhesions that, when once freed, allow for ease of movement. In a preliminary study by Sherlock and Eversaul the effects of a single AquaStretch™ session on lower extremity ROM in healthy student athletes were investigated. The authors found a significant improvement in various lower extremity goniometric measurements, similar to the current study. Sherlock and Eversaul utilized healthy participants and the same 30-minute session as the participants in the current study. In the current study the investigators added in ankle inversion/eversion and functional performance measures and PRO instrument measures. Sherlock and Eversaul found that 25% of the goniometric measurements from pre-/post-intervention were statistically significantly different whereas in the current study the investigators found that uninjured limbs statistically improved their goniometric measurements but none of the injured limbs showed statistically significant differences. This was surprising to the investigators of the current study. The only range of motion measurement that trended towards a significant difference in the injured limb was hip extension while
all other range of motion measurements were not significantly different. These results do not reflect the findings of Sherlock and Eversaul. The results of the current study suggest that follow-up studies need to extend the intervention for longer than one intervention of 30 minutes to explore the effect of more than one treatment session and to determine the appropriate dosage of intervention over time for specific lower extremity dysfunctions.

The current study had several limitations. The recreational athletes in the current study were not restricted from participating in athletic activities prior to or immediately after testing sessions. This lack of control may or may not have contributed to the effects of the intervention as well as participants were not blinded to the intervention performed and were a sample of convenience which may have impacted how they responded to the intervention. Another limitation was that the testers were third-year physical therapy students. The students practiced repeated measures of all tests to improve their testing reliability and were supervised by a faculty member, but lack of experience and not repeating measurements may have contributed to possible error in testing measurements. Future studies should include experienced physical therapists to improve reliability of the testers. Finally, the current study used a single session of AquaStretch™ with the participants completing questionnaires and postintervention measurements immediately after the session without long-term, follow-up investigation. The long-term effect of AquaStretch™ is unknown and requires more investigation.

CONCLUSIONS
The results of the current study indicate that a single 30-minute AquaStretch™ intervention session improved the function of the recreational athletes with LE injury, as measured by the LEFS and FAAM Sports subscale. However, these changes in function were not clinically significant. The athlete’s uninjured limb improved compared to the injured limb. While AquaStretch™ improved functional outcome measure scores; the short-term benefits on ROM, muscle length, and functional movements were not statistically significantly different. Future studies may need to extend the intervention for longer than one intervention of 30 minutes in order to explore the effect of more than one treatment session and to explore the appropriate dosage of this type of intervention for specific lower extremity dysfunctions.

REFERENCES


ABSTRACT

**Background:** Many organizations have introduced frameworks to reduce the incidence of football related concussions through proper equipment fitting, coach education, and alteration of tackling technique.

**Purpose:** The purpose of this study was to examine the effects of training in a vertical, head up tackling style on the number of head accelerations experienced while tackling in a controlled laboratory situation. The authors hypothesized that training in a head up tackling technique would reduce the severity of head acceleration experienced by participants.

**Design:** Controlled Laboratory Study.

**Methods:** Twenty-four participants (11.5 ± 0.6 years old, 60.5 ± 2.2 in, 110 ± 18.4 lbs.) with previous playing experience completed a one-day training session on tackling technique utilizing a tackling dummy. A sub-group of these participants completed an additional two days of training with a 48 hour retention test. Head accelerations were analyzed at baseline and end of training. Feedback consisted of verbal feedback utilizing the Qualitative Youth Tackling Scale (QYTS) and video tackling playback.

**Results:** A significant reduction in the number of peak linear head accelerations over 10 g and peak rotational head accelerations over 1885 deg/s² were found in dummy tackling after training in both the one day and three day training regimens. A significant change in QYTS tackling form score was found between pretest and post-test (p = 0.004). Participants with larger steps had a 2.28, 4.42 and 4.14 increased odds ratio of sustaining head accelerations over 10, 15 and 20 g respectively.

**Conclusions:** Training in a vertical, head up tackling style decreased the number of head accelerations over threshold values sustained while tackling; decreased step length may be the driving factor in the effectiveness of this tackling form.

**Level of Evidence:** Level 3b

**Key Words:** Biomechanics, concussion, head injury, prevention
INTRODUCTION

Concussions in high school football occur at a rate of 6.71 injuries per 10,000 athlete exposures, this number jumps to 30.07 injuries per 10,000 athlete exposures in competition. Head contact during blocking and tackling are the most prevalent mechanism of injury or activity associated with concussion in American football. Despite continued efforts to reduce the occurrence of concussion the incidence continues to increase. Recent research has indicated the effectiveness of Heads Up Football (HUF) framework in reducing head accelerations and injury rates in youth football athletes. However, previous research does not separate the effectiveness of the coaches’ education program, practice restrictions and the vertical, head up tackling technique instructed in these programs.

Concussion rates for youth football athletes per the Youth Football Surveillance Network accounted for 9.6% of all injuries in youth football. The injury rate at this level during game play was 2.38 to 6.16 per 1000 athlete exposures and 0.24 to 0.59 per 1000 exposures in practice. The median and 95th percentile linear acceleration and rotational acceleration for 9-12 year old athletes was significantly different between games and practices, with game accelerations being higher. This trend does not carry forward into 12-14 year olds, who show no difference in accelerations experienced between practice and games.

Recent research may indicate the effectiveness of the HUF program in reducing head accelerations and injury rates in youth football athletes. The HUF program provides league coaches receive hands on training regarding proper equipment fitting, didactic and participant demonstration of proper tackling technique and instruction in drills that reduce head contact, as well as general player safety. The HUF tackling framework provides coaches with a progression of drills designed to implement a head up, vertical tackling style. Participants in HUF leagues experienced fewer head impacts during practice registering both 10 and 20 g when compared to non-HUF leagues. A 10 g head impact cut off value is often utilized in the literature for counting of number of head contacts. However, a count of number of impacts rather than measurement of impact values has also been utilized due to concern over the accuracy of the measurements provided by current technology. In Pop Warner football leagues that also utilized the HUF program also saw a decrease in practice concussion rates (0.14/1000 athlete exposures) when compared to non-HUF leagues (0.79/1000 athlete exposures) though it is unclear whether these changes are due to contact restrictions or tackling style.

The Qualitative Youth Tackling Scale (QYTS) is a visually observed, objective based scale created to instruct a vertical, head up tackling form that mimics the form recommended by USA Football (Figure 1). This scale is designed to provide feedback on the components of the technique believed to be most related to safety while maintaining performance. This system applies quantifiable, objective actions during the tackle to a subjective feedback mechanism that aligns with the overall form requirements of the HUF tackle. To determine an overall score participants are subjectively assigned a point for successful completion of the movement measure. Item 1, short steps, is a measureable variable to represent the “Breakdown” and “Buzz” phases in which the tackler comes under control after pursuit but remains able to adapt to the opponents movements. Item 2, posterior to anterior movement of the arms, aligns with the “Rip” phase of movement which encourages wrapping up as well as using the arms to encourage an upright posture. Item 3, low center of mass, is the first phase of the “Shoot” parameter. Starting low allows the player to extend the hips on contact and initiate a rising blow on contact. Item 4, head across the front, establishes the head outside of the contact zone and encourages tacklers not to lead with the head. Item 5, contact with the front of the shoulder, was again an encouragement to remove the head from contact by encouraging an alternate first point of contact. Item 6, maintain and extended neck position, is part of standard safe practices as contact with the crown of the head increases the risk of cervical spine injury. Items 4, 5 and 6 do not align directly with stated HUF goals but are implied within the tackling methodology and are well known safe tackling procedures.

Utilization of HUF practice recommendations has been indicated to have the potential to decrease injury risk in youth athletes, though the effect of the tackling
The six portions of the Head Up Football tackle form given as instruction and feedback to the participants.
the motion capture laboratory. At the baseline time point, the participants were instructed to “tackle the dummy as they typically do when playing football.” After five baseline tackles, participants were then given instruction on the six standard components of a heads up, vertical style tackle which are contained in the QYTS (Table 1) and allowed three practice trials. Reflective verbal feedback and video feedback utilizing the QYTS was then provided in four blocks of three trials. For the reflective verbal feedback, the participants were given 15 seconds to indicate with a check mark the portions of the tackling movement they performed correctly. They were then provided with the rater’s evaluation of their performance on the same six variables over an additional 15 seconds. Video feedback consisted of one tackle from the previous block of practice played four times at half speed during which participants were instructed to focus on the portions of the QYTS which they did not perform correctly. Playback of the video would occur over 10 seconds with a 10 second break between viewings. The verbal and video feedback were completed over two minutes at the end of each of the training blocks.

Participants in the three day feedback group completed two additional practice sessions with a rest day between sessions. Training during this period consisted of four blocks of three trials with feedback as provided on day one. The participants then returned to the lab after a 48-hour retention time period. During the retention testing the participants performed five additional tackles in the same manner as training with no feedback given before or during testing.

Head acceleration data were collected utilizing data captured by the xPatch system. Two xPatch systems were applied bilaterally to the participant’s mastoid processes utilizing manufacturer provided adhesive patches. The threshold for recording impacts was set at 6 g for each device to allow for data collection below the 10g cut off. Previous reporting of head impact data has routinely utilized the 10g recording activation of these devices to determine the number of head impacts received during participation.8–10 Data were downloaded from the xPatch device into the X2 Impact Monitoring system (X2 Biosystems; Seattle, WA) using the manufacturer’s procedure. The data were uploaded and processed utilizing the system software which adjusts measures based on right and left head side device placement, making right and left side data comparable, and translates the measurements to the center of mass of the head. Peak linear acceleration (PLA) and peak rotational acceleration (PRA) measures as calculated by the system were downloaded to an Excel spreadsheet. Also included in this spreadsheet were: the time of

| Table 1. The Qualitative Youth Tackling Scale, including objective measures. Subjective information was provided as verbal feedback to participants. |
|---|---|
| **Subjective Feedback** | **Objective Measure** |
| 1. The athlete to maintain body control with short steps. | Step length less than 75% of standing pelvic height over last 250 cm to target. |
| 2. Utilize the arms in a posterior to anterior motion during the tackle. | Shoulder extension greater than 45 degrees during last 0.5 seconds prior to contact. |
| 3. Lower the body center of mass by bending at the knees. | Average Pelvis height less than 75% of standing pelvic height over last 0.25 seconds prior to contact. |
| 4. Keep the head across the front of the target and not allow it to make contact with the target. | Visual verification of head placement on opposite side of approach on contact. |
| 5. Contact the target with the front of the shoulder to keep the head away from the target. | Trunk angle between 35 and 55 degrees relative to ground on contact. |
| 6. Keep the neck in an extended position by seeing the target to avoid contact with the crown of the head. | Cervical extension over 45 degrees on contact. |
Impact, location, duration, and Clack measurement. The Clack measurement is an algorithm utilized by the monitoring system to distinguish true impacts from accidental bumping or dropping of the device. The xPatch system has been found to have a high correlation to the forces experienced by the wearer but routinely over estimates the measure of these forces.\textsuperscript{11}

Impacts were identified by comparing the timestamp reported by the xPatch device with the video recording of the data collection. The time stamp on the xPatch and the monitor were synced immediately prior to initiation of data collection. The monitor and the xPatch were both capable of displaying the time to within $1/100^{th}$ of a second. Because impacts were aligned by time stamp on the device and video recording all impacts were utilized regardless of the Clack measurement, as it was independently verifiable the measure was not from a dropped device. Impacts from the left and the right xPatch were identified from the full list of all 6 g and above PLA recordings and were averaged. If two impacts took place in rapid succession, the first of the impacts was utilized. The second impact was likely caused by contact with the ground at the completion of the movement which is not the focus of this study.

Physical movement data was collected utilizing a 10 camera Vicon motion capture system (Vicon; Oxford, UK) and a modified Helen Hayes marker set. A 58 marker set was used over bilateral lower extremities, upper extremities to the elbow, pelvis, torso and an adapted wrestling head gear to provide stable marker placement on the head (Figure 2).

Statistical analyses consisted of Wilcoxon Signed Ranks Tests to determine the effect of training on participant counts of PLA and PRA over threshold levels at baseline and the last training block for one day training ($n=24$) and between baseline and 48 hour retention testing for the three day group ($n=14$). For the one-day training group the first three baseline tackles were compared to the final three tackles of the day's training. For the three-day group all five baseline tackles were compared to the five tackles performed during retention testing. A median split was calculated for PRA data during baseline tackles for all participants. This number was then utilized as a threshold. An additional Wilcoxon Signed Ranks Test was performed to determine the effect of training on all training participant scores of the QYTS at one day pretest and post-test time points. For the one-day training group the first three baseline tackles were compared to the final three tackles of the day's training. For the three-day group all five baseline tackles were compared to the five tackles performed during retention testing. A median split was calculated for PRA data during baseline tackles for all participants. This number was then utilized as a threshold. An additional Wilcoxon Signed Ranks Test was performed to determine the effect of training on all training participant scores of the QYTS at one day pretest and post-test time points. A Mann-Whitney $U$ test was performed to evaluate if a difference exists between QYTS scores of those who experienced head accelerations greater or less than 10g between one day time points. Statistical significance values were set at \textit{a priori} $p<0.05$ for all tests. Odds ratios comparing the successful performance of the individual skills of the QYTS to

Figure 2. A fifty-eight marker set was utilized to determine neck, trunk, pelvis, hip, knee, ankle, shoulder and elbow angles. The modified wrestling headgear minimized head marker movement during contact drills.
head accelerations over 10, 15, and 20g were also completed.

RESULTS
In the 72 tackles (three tackles each, in 24 participants) performed during the baseline testing the mean impact count was $1.2 \pm 0.9$ and ranged from zero impacts to three impacts per participant. After training the mean impact count was $0.6 \pm 0.7$ per participant ranging from zero impacts to two impacts per participant. Individual change scores are indicated in Figure 4A. Results of the Wilcoxon Signed Ranks Test indicated a significant difference between these two timepoints ($p=0.027, Z=-2.216, df=18$). In the three-day training group ($n=14$) PLA counts over 10g averaged $1.9 \pm 1.6$ and ranged from zero to five per participant at baseline. After training this number decreased to $0.5 \pm 1.2$ and ranged from zero to five. Individual change scores are indicated in Figure 4C. Results of the Wilcoxon Signed Ranks Test indicated a significant difference between these two time points ($p=0.021, Z=-2.313, df=10$).

Peak Rotational Acceleration (PRA) data was median split to create a threshold measure of 1885 deg/s$^2$. The mean impact count was $1.2 \pm 0.9$ and ranged from zero impacts to three impacts per participant. After one day of training, the mean impact count

![Figure 3. Number of impacts over 10g for each participant in the 1 day treatment group, chart A (n=24) and 3 day treatment group, chart B (n=14).](image-url)
was 0.5 ± .7 per participant. This number ranged from two impacts to zero impacts per participant. Individual change scores are indicated in Figure 4B. Results of the Wilcoxon Signed Ranks Test indicated a significant difference between these two time-points (p = 0.038, Z = -2.079, df = 19). In the three-day training group PRA counts over 1885 deg/s² averaged 1.9 ± 1.7 and ranged from zero to five per participant at baseline. After training this number decreased to 0.6 ± 1.2 and ranged from zero to four. Individual change scores are indicated in Figure 4D. Results of the Wilcoxon Signed Ranks Test indicated a significant difference between these two time-points (p = 0.042, Z = -2.038, df = 11).

To assess change in performance between baseline and after one day of training, the participant’s movement profile from motion capture data was dichotomized for along the criteria for each aspect of the QYTS. The dichotomized score was summed to create an overall score for each tackle. A Wilcoxon Signed Rank Test was performed between the two time points. This test indicated a difference in the total score between the baseline and end of one day training time points (p = .004, Z = -2.915, df = 17). The average QYTS score improved from 1.50 ± 1.10 to 2.46 ± 1.31.

In an examination of all head acceleration data points regardless of time point, a Mann Whitney U test found no significant difference (p = .281, Z = -1.079, df = 261) in QYTS scores during tackles in which the participant’s head acceleration measurement was over 10g when compared to those tackles that were below the 10g threshold. Odds ratios (Table 2) calculated for all movements found increased odds of having head acceleration greater than 10g when participants had an average step length greater than 75% of standing pelvis height (2.28, 95% CI: 1.29-4.05). Similar tests for trunk inclination greater than 55 degrees or less than 35 degrees (1.09, 95% CI: 0.61-1.96), cervical extension less than 45 degrees (0.96, 95% CI: 0.57-1.62) pelvis height greater than 75% of standing pelvis height (1.68, 95% CI: 0.93-3.01) and shoulder extension on approach less than 45 degrees (0.61, 95% CI: 0.35-1.08) were non-significant. The odds of sustaining an impact over 15g (4.42, 95% CI: 1.80-10.80) and 20g (4.14, 95% CI: 1.40-12.29) were also increased with a step length greater than 75% of pelvis height and for pelvis height over 75% of standing pelvis height at 15g (3.10, 95% CI: 1.26-7.61).

**DISCUSSION**

The results of this study indicate that training in a head up, vertical style tackle reduces the number of head accelerations over 10 g and 1885 deg/s² experienced by the tackler. Previous research has indicated the effectiveness of the USA Football Heads Up program overall to decrease the number of head accelerations experienced by tacklers.8 The USA Football Heads Up program provides coaches with a prescribed tackling form along with instructions to reduce the number of high contact drills which may be responsible for the decrease in head accelerations experienced in this previous study. Concurrently with the decrease in head accelerations, the participants’ form scores on the QYTS improved from baseline to post training. Results indicated

| Table 2. Odds ratios of experiencing head acceleration over 10, 15 and 20g’s by failed performance of Qualitative Youth Tackling System items. Significant odds ratios indicated by darkened sections. |
|---|---|---|---|
|   | 10G | 15G | 20G |
| Cervical Extension | 0.96 | 1.46 | 0.89 |
| Trunk Inclination | 1.09 | 1.88 | 2.20 |
| Head Placement | 1.46 | 0.63 | 0.5 |
| Pelvic Height | 1.68 | 3.10 | 2.2 |
| Shoulder Extension | 0.61 | 0.32 | 0.37 |
| Step Length | 2.28 | 4.42 | 4.14 |

95%CI: 0.57-1.62  95%CI: 0.73-2.89  95%CI:0.41-1.98  95%CI:0.80-4.41  95%CI:0.74-6.55  95%CI:0.59-2.59  95%CI:0.14-2.79  95%CI:0.65-3.90  95%CI:0.93-3.01  95%CI:1.26-7.61  95%CI:1.08-6.02  95%CI:1.29-4.05  95%CI:1.80-10.80  95%CI:1.40-12.39
those who took shorter steps toward the target had decreased odds ratios of receiving an impact greater than 10, 15 and 20g in one day of training. Participants decreased the head accelerations experienced both immediately during a one day training session and in a 48 hour retention with three sessions of training.

Analysis of changes in form indicates the training program was successful in improving the QYTS scores of the athletes over a one day period. Of these changes in form, a significant increase in the odds ratio of suffering an impact over 10, 15 and 20g was found in those who failed to reduce their step length to less than 75% of standing pelvis height. This result may indicate that slowing the body in general decreases the head accelerations experienced or increases the time of approach, allowing the tackler to achieve better form as they apply the tackle. Other portions of the QYTS may show higher odds of head accelerations above 15 and 20g, however these data were limited to few impacts above those levels possibly due to the laboratory design as well as the age of the participants.

Linear accelerations and rotational acceleration/velocity have been proposed as the causative factors of concussive injuries, with a significant relationship between linear and rotational components. Previously only impacts that resulted in a concussion were seen as dangerous. As knowledge regarding head injuries increases, the role of subconcussive blows in long term health effects has become better known. Some research has indicated the effect of subconcussive impact includes increased risk of mild cognitive impairment and chronic traumatic encephalopathy (CTE). Providing a form structure that limits both high level impacts and subconcussive blows may lead to reduced concussive injury rates and long term cognitive issues. The results of this study indicate a training program in tackling form is capable of significantly decreasing the number of head contacts over 10g.

The performance of a tackle that minimizes head accelerations is critical to the safety of the athletes in youth football. The results of this study indicate training in a head up vertical style tackle reduces the head accelerations experienced by tacklers in a laboratory setting against a stationary target. These results are critical to determining a form that minimizes the head accelerations experienced. These results provide a baseline from which additional research should be planned to translate these results to a field based dynamic environment.

CONCLUSION
The performance of a tackle that minimizes head accelerations is critical to the safety of the athletes in youth football. The results of this study indicate training in a head up vertical style tackle reduces the head accelerations experienced by tacklers in a laboratory setting against a stationary target. These results are critical to determining a form that minimizes the head accelerations experienced. These results provide a baseline from which additional research should be planned to translate these results to a field based dynamic environment.

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ABSTRACT

**Background:** Long term neurologic injury and concussion have been identified as risks from participation in American football. Altering tackling form has been recommended to reduce the risk of neurologic injury caused by head accelerations when tackling. The purpose of this research is to determine the inter-rater agreement and validity of the Qualitative Youth Tackling System (QYTS), a six-item feedback scale to correct tackling form, when utilized by novice and expert raters.

**Hypothesis:** Experienced raters will have higher levels of agreement with each other and with motion capture when compared to novice raters.

**Methods:** Both novice and experienced raters viewed video of youth athletes (ages 9-13) tackling a dummy in a laboratory setting along. The raters identified successful performance according to a binary rating scale for each component. Analysis of both the raters' agreement with each other and with an objective motion capture measure were completed.

**Results:** Fliess' Kappa measures between all raters were found to be moderate for head placement (k = .48), fair for cervical extension (k = .38), trunk inclination (k = .37), shoulder extension (k = .27) and step length (k = .29), and there was no agreement for pelvic height (k = .16). When compared to the dichotomized validation measures of each of the five components provided by the motion capture system the average Cohen's Kappa agreement was substantial for pelvic height (k = .63), fair for step length (k = .34), cervical extension (k = .40), trunk inclination (k = .35), and slight for shoulder extension (k = .16). The experienced raters outperformed the novice raters in all categories.

**Conclusion:** The results of this study indicate that skilled raters are better able to identify the movement patterns included in the QYTS when compared to a validation measure as well have higher rates of inter-rater agreement than novice raters.

**Level of Evidence:** 3b

**Keywords:** Concussion, Feedback, Football, Motor Learning
INTRODUCTION
A 2015 position statement by the American Academy of Pediatrics recommended, “officials and coaches must enforce the rules of proper tackling, including zero tolerance for illegal, head-first hits.”¹ Concussions in high school football occur at a rate of 6.71 injuries per 10,000 athlete exposures, this number jumps to 30.07 injuries per 10,000 athlete exposures in competition.² Poor form, creating head contact during blocking and tackling is the most prevalent mechanism of injury or activity associated with concussion in American football.² An appropriate instruction and feedback methodology to improve tackling form has yet to be determined. Verbal feedback is the standard mechanism utilized to improve movement technique in athletes of all ages and sports. The ability to provide consistent and valid feedback is crucial to the success of any coaching intervention, yet often high rates of variability exist in the provision of feedback.

Coaches and medical professionals often visually estimate activity in order to provide feedback. Caution should be exercised when providing feedback developed solely from visual estimation, as this technique can create highly variable feedback. While visual estimation of movement patterns is standard practice in coaching³, the use of additional measurement techniques such as video applications has increased.⁴⁻⁷ Visual estimation of joint motion has been reported to be highly variable with limitations in its accuracy.⁸⁻¹¹ Despite these concerns, visual estimation of movement requires no equipment and can be performed immediately without data processing. Due to this simplicity, visual estimation of movement is commonly utilized in movement instruction and training. Rater training and utilization of standardized procedures has been shown to improve rater agreement in assessment of dynamic movements.¹²⁻¹⁴

Providing consistent feedback to learners is important to develop the skill being learned. When developing motor strategies, learners are better able to attain a higher level of performance when the model or feedback they receive is consistent.¹⁵⁻¹⁹ Combined feedback from visual estimation and other sources are common in feedback mechanisms and with training can be reliable. The purpose of this study was to identify the inter-rater agreement and validity of a six-criteria tackling scale utilizing video review. Identification of the rater’s ability to provide both consistent and accurate feedback is important in developing training tools to improve tackling form. The development of a standardized tackling feedback tool will give sport and movement coaches the ability to provide appropriate feedback both in a verbal only mechanism as well as in combination with other modalities. Therefore, the purpose of this research is to determine the inter-rater agreement and validity of the Qualitative Youth Tackling System (QYTS), a six-item feedback scale to correct tackling form, when utilized by novice and expert raters.

METHODS
The Qualitative Youth Tackling Scale (QYTS) is a head up, vertical style tackle developed to limit athlete head contact while completing an effective tackle. The QYTS (Figure 1) is a visually observed, objective based scale created to instruct a vertical, head up tackling form that mimics the Heads Up Tackle® form previously recommended by USA Football.²⁰ This scale is designed to provide feedback on the components of the technique believed to be most related to safety while maintaining performance. This system applies quantifiable, objective actions during the tackle to a subjective feedback mechanism that aligns with the overall form requirements of the Heads Up Tackle®. To determine an overall score, participants are subjectively assigned a point for successful completion of the specified movement measure.

Inter-rater agreement was examined utilizing two experienced clinicians with six (ATC) and ten years (PT, ATC) of post-certification experience, respectively, and two novice raters with no formal training in movement evaluation. All participants were informed of the benefits and risks of participating in this study and signed an IRB approved consent form. Participants were provided with an interactive text and video training module on the components of the Qualitative Youth Tackling Scale (QYTS). The rater training included an explanation of the correct tackling form, examples of expert tackling, and an immediate feedback pre-test utilizing video examples of youth athletes performing both correct and
incorrect tackling. Each rater reported their evaluation of the performance as correct or incorrect as it pertained to the guidelines for each movement item. Participants were required to achieve 80% accuracy on the pre-test prior to rating experimental trials. The total time spent on the training prior to rating the experimental videos was recorded to determine training exposure. Participants were then given 20 video trial examples to rate independently. The raters were able to review the video as many times as needed and were given full control over the playback of each video. The total time to complete the rating was recorded. Overall rater agreement was calculated utilizing a Fleiss' Kappa score. Rater agreements between two experienced, two novices and between experienced and novices were calculated utilizing Cohen's Kappa scores and positive (PA) and negative agreement (NA).

In order to understand the relationship between the raters' evaluation of the performance and the movement being performed, agreement between the raters' scores and a validation standard were performed utilizing a dichotomous split of the motion capture data, within or outside of the desired range of motion of the movement goal, to calculate averaged Cohen's Kappa scores, PA and NA. Because accurate visual estimation is inherently difficult, the validation measure was dichotomized in increasing bands of five percent accuracy from 100% to 80% using a Banded Cohen's Kappa. This expanding band is utilized to determine the potential accuracy of raters. An increasing rate of agreement indicates the raters could be more accurate if they are allowed increased latitude with their response. A decreasing trend indicates increased latitude does not positively affect the agreement outcome and the raters were already at their highest level of agreement. A level line indicates no change in agreement with increased latitude and that the measure is stable. For example, the dichotomized acceptable shoulder movement was adjusted in increments of 5% of 45°: 95% = 42.75°, 90% = 40.5°, 85% = 38.25, 80% = 36°. Averaged Cohen's Kappa scores, PA and NA were then calculated for each point to determine if an expanded definition of accuracy increased rater agreement.

RESULTS

Fleiss' Kappa measures between all raters were found to be moderate for head placement ($k = .48$), fair for cervical extension ($k = .38$), trunk inclination ($k = .37$), shoulder extension ($k = .27$) and step length ($k = .29$), and there was no agreement for pelvic height ($k = .16$) (Table 1). Cohen's Kappa measures...
between experienced found substantial agreement between ratings of cervical extension ($k=.69$), head placement ($k=.61$), pelvic height ($k=.73$) and shoulder extension ($k=.70$). Step length results indicate moderate agreement ($k=.49$) and trunk inclination results indicate fair agreement ($k=.24$) (Table 2). Cohen’s Kappa measures between the two novice raters found moderate agreement for head placement ($k=.41$). Step length ($k=.34$), trunk inclination ($k=.40$), and shoulder extension ($k=.34$) were found to have fair agreement. Slight agreement was found for cervical extension ($k=.15$) and pelvic height ($k=.11$) (Table 3).

When compared to the dichotomized validation measures of each of the six components provided by the motion capture system the Experienced rater’s average Cohen’s Kappa agreement was substantial for pelvic height ($k=.68$), moderate for step length ($k=.44$) and cervical extension ($k=.55$) and fair for trunk inclination ($k=.31$) and shoulder extension ($k=.27$) (Table 4). The novice raters had lower levels of agreement, moderate for pelvic height ($k=.57$), fair for cervical extension ($k=.25$), trunk inclination ($k=.39$), and step length ($k=.24$) and slight for shoulder extension ($k=.05$) (Table 5).

Banded Cohen’s Kappa comparisons utilizing averaged measures from raters and the values derived from motion capture found increasing agreement in measures of trunk inclination ($k=.35$ to .50) and shoulder extension ($k=.16$ to .50) with decreasing required accuracy while the agreement between raters and motion capture in pelvic height ($k=.62$)

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### Table 1. Fleiss Kappa Measures between all raters.

<table>
<thead>
<tr>
<th></th>
<th>Cervical extension</th>
<th>Trunk Inclination</th>
<th>Head placement</th>
<th>Pelvic height</th>
<th>Shoulder extension</th>
<th>Step length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fleiss’ Kappa</td>
<td>0.38</td>
<td>0.37</td>
<td>0.48</td>
<td>-0.16</td>
<td>0.27</td>
<td>0.29</td>
</tr>
<tr>
<td>Lower Bound</td>
<td>0.20</td>
<td>0.19</td>
<td>0.30</td>
<td>-0.34</td>
<td>0.09</td>
<td>0.11</td>
</tr>
<tr>
<td>Upper Bound</td>
<td>0.55</td>
<td>0.54</td>
<td>0.66</td>
<td>0.02</td>
<td>0.45</td>
<td>0.47</td>
</tr>
</tbody>
</table>

Fleiss Kappa Measures: Almost Perfect: 0.81-1, Substantial: 0.61-0.80, Moderate:0.41-0.60, Fair: 0.21-0.40, Slight: 0-0.20. Negative scores indicate no agreement between scoring.

### Table 2. Cohen’s Kappa, Positive and Negative Agreement percentage between AT raters.

<table>
<thead>
<tr>
<th></th>
<th>Cervical extension</th>
<th>Trunk Inclination</th>
<th>Head placement</th>
<th>Pelvic height</th>
<th>Shoulder extension</th>
<th>Step length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cohen’s Kappa</td>
<td>0.69</td>
<td>0.24</td>
<td>0.61</td>
<td>0.73</td>
<td>0.70</td>
<td>0.49</td>
</tr>
<tr>
<td>Positive Agreement</td>
<td>87%</td>
<td>40%</td>
<td>94%</td>
<td>80%</td>
<td>84%</td>
<td>60%</td>
</tr>
<tr>
<td>Negative Agreement</td>
<td>82%</td>
<td>80%</td>
<td>67%</td>
<td>93%</td>
<td>86%</td>
<td>87%</td>
</tr>
</tbody>
</table>

Cohens Kappa Measures: Almost Perfect: 1-0.81, Substantial: 0.80-0.61, Moderate: 0.60-0.41-, Fair: 0.40-0.21, Slight: 0.20-0.

### Table 3. Cohen’s Kappa Positive and Negative Agreement percentage between Novice Raters.

<table>
<thead>
<tr>
<th></th>
<th>Cervical extension</th>
<th>Trunk Inclination</th>
<th>Head placement</th>
<th>Pelvic height</th>
<th>Shoulder extension</th>
<th>Step length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cohen’s Kappa</td>
<td>0.15</td>
<td>0.40</td>
<td>0.41</td>
<td>0.11</td>
<td>0.34</td>
<td>0.34</td>
</tr>
<tr>
<td>Positive Agreement</td>
<td>64%</td>
<td>57%</td>
<td>88%</td>
<td>57%</td>
<td>52%</td>
<td>77%</td>
</tr>
<tr>
<td>Negative Agreement</td>
<td>40%</td>
<td>77%</td>
<td>50%</td>
<td>53%</td>
<td>35%</td>
<td>57%</td>
</tr>
</tbody>
</table>

Cohens Kappa Measures: Almost Perfect: 1-0.81, Substantial: 0.80-0.61, Moderate: 0.60-0.41-, Fair: 0.40-0.21, Slight: 0.20-0.
to .00) comparisons decreased with decreasing required accuracy (Figure 2). Banded positive agreement increased between 100% and 90% accuracy for step length (51% to 57%) and trunk inclination (50% to 65%), while shoulder extension continued to improve (35% to 78%) through 80% of the validity measure (Figure 3). Banded negative agreement remained stable for all measures with the exception of pelvic height which decreased from 86% agreement at 100% of the validity measure to 75% at 90% of the validity measure then sharply to 0% at 80% of the validity measure (Figure 4). Average time to complete the training was 34 ± 8 minutes. Average time to complete the rating of the 20 videos was 20.5 ± 3 minutes.

**DISCUSSION**

Raters of the QYTS obtained substantial to slight agreement (dependent on the specific movement) when identifying the movements performed during a tackle when compared between themselves, experienced to novice, and themselves to motion capture (a validation standard). A higher degree of accuracy and agreement was found between raters with experience evaluating human movement. Raters with movement evaluation training (Physical Therapists and Athletic Trainers) had higher levels of agreement than non-certified novices through most movements as well as a higher level of agreement with the validation measurements when compared to the novice raters. Banded Kappa analysis indicated the agreement between raters improved when accepting a lower percentage of accuracy compared to the motion capture system for measures of shoulder extension and trunk inclination, decreased agreement at lower measures of accuracy for pelvic height and no change for step length and cervical angle.

**Table 4. Cohen’s Kappa Positive and Negative Agreement percentage between rater and validation measure for AT raters.**

<table>
<thead>
<tr>
<th></th>
<th>Cervical extension</th>
<th>Trunk Inclination</th>
<th>Pelvic height</th>
<th>Shoulder extension</th>
<th>Step length</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cohen’s Kappa</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rater 1</td>
<td>0.50</td>
<td>0.15</td>
<td>0.74</td>
<td>0.30</td>
<td>0.39</td>
</tr>
<tr>
<td>Rater 2</td>
<td>0.60</td>
<td>0.48</td>
<td>0.63</td>
<td>0.24</td>
<td>0.48</td>
</tr>
<tr>
<td>Average</td>
<td>0.55</td>
<td>0.31</td>
<td>0.68</td>
<td>0.27</td>
<td>0.44</td>
</tr>
<tr>
<td><strong>Positive Agreement</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rater 1</td>
<td>76%</td>
<td>36%</td>
<td>80%</td>
<td>46%</td>
<td>55%</td>
</tr>
<tr>
<td>Rater 2</td>
<td>82%</td>
<td>57%</td>
<td>73%</td>
<td>40%</td>
<td>57%</td>
</tr>
<tr>
<td>Average</td>
<td>79%</td>
<td>47%</td>
<td>76%</td>
<td>43%</td>
<td>56%</td>
</tr>
<tr>
<td><strong>Negative Agreement</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rater 1</td>
<td>74%</td>
<td>76%</td>
<td>93%</td>
<td>74%</td>
<td>83%</td>
</tr>
<tr>
<td>Rater 2</td>
<td>78%</td>
<td>91%</td>
<td>90%</td>
<td>80%</td>
<td>91%</td>
</tr>
<tr>
<td>Average</td>
<td>76%</td>
<td>83%</td>
<td>91%</td>
<td>77%</td>
<td>87%</td>
</tr>
</tbody>
</table>

Cohens Kappa Measures: Almost Perfect: 1-0.81, Substantial: 0.80-0.61, Moderate: 0.60-0.41, Fair: 0.40-0.21, Slight: 0.20-0.

**Table 5. Cohen’s Kappa Positive and Negative Agreement percentage between rater and validation measure for Novice raters.**

<table>
<thead>
<tr>
<th></th>
<th>Cervical extension</th>
<th>Trunk Inclination</th>
<th>Pelvic height</th>
<th>Shoulder extension</th>
<th>Step length</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cohen’s Kappa</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rater 1</td>
<td>0.30</td>
<td>0.38</td>
<td>0.44</td>
<td>0.01</td>
<td>0.24</td>
</tr>
<tr>
<td>Rater 2</td>
<td>0.20</td>
<td>0.40</td>
<td>0.69</td>
<td>0.10</td>
<td>0.24</td>
</tr>
<tr>
<td>Average</td>
<td>0.25</td>
<td>0.39</td>
<td>0.57</td>
<td>0.05</td>
<td>0.24</td>
</tr>
<tr>
<td><strong>Positive Agreement</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rater 1</td>
<td>63%</td>
<td>50%</td>
<td>67%</td>
<td>25%</td>
<td>47%</td>
</tr>
<tr>
<td>Rater 2</td>
<td>69%</td>
<td>57%</td>
<td>80%</td>
<td>31%</td>
<td>47%</td>
</tr>
<tr>
<td>Average</td>
<td>66%</td>
<td>54%</td>
<td>73%</td>
<td>28%</td>
<td>47%</td>
</tr>
<tr>
<td><strong>Negative Agreement</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rater 1</td>
<td>67%</td>
<td>88%</td>
<td>73%</td>
<td>50%</td>
<td>61%</td>
</tr>
<tr>
<td>Rater 2</td>
<td>43%</td>
<td>77%</td>
<td>88%</td>
<td>67%</td>
<td>61%</td>
</tr>
<tr>
<td>Average</td>
<td>55%</td>
<td>82%</td>
<td>80%</td>
<td>58%</td>
<td>61%</td>
</tr>
</tbody>
</table>

Cohens Kappa Measures: Almost Perfect: 1-0.81, Substantial: 0.80-0.61, Moderate: 0.60-0.41, Fair: 0.40-0.21, Slight: 0.20-0.
Overall agreement measures between raters found fair agreement between all raters. When rating cervical extension, trunk inclination, head placement, shoulder extension and step length the raters were able to achieve Fleiss’ Kappa ratings within the fair (k = .21 to .41) range. While agreement may be low in these results, the outcomes are comparable to other studies of visual estimation\(^9,11,12,21\) and better than...
Visual estimation of movement is often hampered by difficulty judging the movements produced. This result is seen across many areas of study, such as knee motion during running and cervical spine motion. In the case of the QYTS, the raters were able to utilize video playback to improve their evaluation of the movement, though the results of this study may have been affected by the number of variables evaluated and the use of one camera angle.

Physical Therapists, Athletic Trainers and other human movement practitioners are experienced in evaluating human movement. This training may explain why experienced raters were able to achieve both higher agreement between raters and between raters and the validity measures. In their training, human movement practitioners would have been exposed to many cases of evaluating movement visually. This may have allowed the raters to gain a perspective or evaluation technique to improve their accuracy and reliability when viewing human movement. Human movement practitioners also have a better understanding of the visual appearance of the range motion referenced in the training, having had experience measuring and evaluating movement.

They are likely better able to understand the reference to 45 degrees of shoulder extension during QYTS training, having measured such movements themselves as part of their training. The increased agreement seen in both the inter-rater comparison and between experienced raters and validity measures may be a function of the additional training of the experienced raters.

In the banded Kappa analysis, when the percentage of accuracy required by the validity rating is reduced, the validity agreement for trunk inclination and shoulder extension improved. This result indicates raters were capable of higher agreement with less stringent requirements. They were less able to identify the movement exactly, but a small allowance in the accuracy requirement increased their agreement. As the accuracy required was reduced, shoulder extension agreement improved across all bands. While it appears that raters had difficulty identifying movements over 45 degrees, they were able to separate those who extended the shoulder to at least 80% of the desired movement profile. Further investigation reveals raters consistently responded affirmatively down to 50% of the desired rating, or 25 degrees shoulder extension indicating...
their estimation of shoulder range of motion to be a rather course measure. They could not identify a movement difference between 45 degrees and 25 degrees, but could identify that they had passed into a measure beyond 25 degrees and considered that successful shoulder extension. Rating of trunk inclination improved with a shift to 95% accuracy at which time the improvement in agreement stabilized. Raters reached their highest consistency in agreement when the movement was considered correct between 43 and 57 degrees trunk angle. This would indicate raters either just missed correctly identifying the motion correctly or were not close in their estimation. These expanded movement parameters may be satisfactory for proper execution of the tackle, though this answer is beyond the scope of this project.

Agreement on pelvic height between the raters and motion capture decreased with an increased acceptable range. Raters achieved their highest agreement with 100% accuracy to the pelvic height requirement, indicating they were achieving their best possible accuracy at the desired goal. Accepting measures beyond 100% accuracy caused measures that were correctly identified as outside of the goal motion to be included in the desired range, creating less agreement. Cervical extension and step length measures stayed stable with an expanded range. This indicates raters did not benefit from a relaxation of the standard. This most likely is caused by large errors in the estimated range of motion for those who incorrectly identified the motion.

The pre-assessment training and assessment for the raters may not have been sufficient to ensure a thorough understanding of the method of movement evaluation. The training program for raters should be evaluated, though additional training maybe ineffective due to the inherent limitations of visual estimation of movement. All of these variables may have played a part in the less than perfect agreement seen in the comparison between all raters.

Limitations to this research include a small sample of raters with limited training on the QYTS. Future studies should include a larger cohort of raters, both experienced and inexperienced, who have participated in a more in-depth training program. This research also only identifies trends in video evaluation of the movement, real-time rating of movement presents a different set of requirements and should be considered separately. Coaches, trainers and health care professionals often provide verbal feedback to players without the aid of video; thusly additional research should examine the ability of the QYTS to be utilized in real time. Additional research should also examine the intra-rater reliability of the QYTS scale over time.

CONCLUSION
The results of this study indicate that the inter-rater agreement and validity measures for the QYTS show a range of agreement from substantial to slight across the five rated movement components. With refinement this system may function as a mechanism to provide feedback during video review of tackling practice in American football. More experienced and movement trained raters showed a higher level of agreement both with each other and with a validation standard. It is important when providing feedback during motor learning that the learner to be provided with consistent and correct information regarding their performance. This study indicates those with more experience analyzing human movement are able to provide more accurate and reliable feedback to the learner.

REFERENCES
6. Hewett TE, Torg JS, Boden BP. Video analysis of trunk and knee motion during non-contact anterior


ABSTRACT

Background: Blood flow restriction (BFR) applied during low intensity exercise produces hypertrophy and strength gains equivalent to traditional training. Previous research has shown the positive effects of BFR on younger and older adults. However, the effectiveness of BFR on subjects with Parkinson Disease (PD) has not been investigated.

Hypotheses/Purpose: The purpose of the study was to determine the effects of BFR on a recreationally active person with PD in regards to functional improvements and safety. The hypothesis was that BFR training will demonstrate improvements in motor function, gait and endurance, while decreasing symptoms associated with Restless Leg Syndrome (RLS) in a subject with PD.

Study Design: A single subject, B-A design was used.

Methods: The subject was an active 65-year-old male recreational boxer diagnosed with PD. Baseline data were measured on day one. The intervention (Phase B) consisted of five, two-minute bouts of walking on treadmill with lower extremity BFR cuffs interspersed with 1 minute rest, three times a week for six weeks, at 0 grade incline, and speed of 50 meters/min. The pressure increased from the initial 120 to 160 mmHg at the end of the phase B as per the subject's tolerance. A four-week baseline phase (A) without the BFR intervention followed phase B. The outcome measures which were measured every two weeks over the 10 weeks included: Timed Up and Go Test, 6-Minute Walk Test, 30-Second Chair Stand Test, and the RLS Questionnaire.

Results: All outcome measures steadily improved every two weeks during the six week intervention phase and steadily declined when the intervention was removed during the second four week baseline phase according to visual inspection of the graphed data points.

Conclusion: The subject enjoyed and tolerated the intervention well without any adverse effects. The results were that BFR training can produce functional improvements, reduce restless leg syndrome symptoms and can be safely utilized with a subject with PD who wishes to maintain his ability to remain recreationally active.

Key words: Blood flow restriction, exercise, single-subject; treadmill, walking.
INTRODUCTION
Parkinson disease (PD) is a debilitating disease of the central nervous system that affects over one million people, over 65 years old in the United States. PD is a chronic disease and is characterized by progressive degeneration of dopaminergic neurons within the substantia nigra. These motor circuits within the basal ganglia are essential for control and coordination of movement. The degeneration of dopaminergic substantia nigra neurons manifests in rigidity, bradykinesia, resting tremors, and impaired postural reflexes. These primary features of PD result in an overall decrease in motor function, muscle strength, level of endurance, and gait efficiency. Restless legs syndrome (RLS) is another symptom specific to PD, which has a prevalence of up to 52% in patients with PD. RLS is a neurological disorder characterized by throbbing, creeping, and other unpleasant sensations in the legs with an uncontrollable, and sometimes overwhelming urge to move them while attempting to sleep.

Aerobic and strength training exercise has been shown to facilitate the brain to produce growth factors to protect dopamine-producing neurons, in order to preserve function of those persons with PD. In the mid-1970’s, Yoshiaki Sato created KAATSU training in Japan. KAATSU training is also known as Blood Flow Restriction training (BFR). BFR involves the application of an external constricting device to provide mechanical compression of the underlying vasculature. BFR applied to an active muscle during low intensity exercise, produces muscular hypertrophy and strength gains equivalent to improvements made from traditional high resistance strength training. The minimum intensity accepted for weight training in order to see strength gains is 65% of a person’s one-repetition maximum (1-RM), for that active muscle group during a particular exercise. Low intensity exercise is either an aerobic exercise or resistance training at 20-30% of a person’s 1-RM. Low intensity resistance training alone has not been shown to provide strength gains. The physiological mechanisms behind BFR are attributed to the increase in metabolic stress induced by the diminished blood flow, potentially leading to increased muscle fiber recruitment during exercise. It also elevates systemic hormonal production and enhanced muscle protein synthesis due to an increase in phosphorylation of proteins in muscle signaling. Low intensity exercise with BFR produces a metabolic overload, with a depletion of phosphocreatine stores and a decrease in the muscle’s pH. This is normally present with higher intensity muscle activation in resistance exercise. BFR has been researched and used on subjects during various forms of exercise including walking and isotonic exercises (grip strength and leg extensions). It may be more beneficial to perform low intensity exercise in older adults because it decreases the stress on joints and musculature. Therefore, the purpose of using BFR and low intensity exercise is to lower the adverse ramifications involved with high intensity exercise training.

Abe et al. investigated the acute and chronic effects of walk training with BFR training on muscle hypertrophy and strength. Eighteen young, healthy men were split into a BFR group and control group. Training was conducted twice a day, six days per week, for three weeks using five sets of 2-minute bouts (treadmill speed at 50 meters/min), with a one-minute rest between bouts. They reported that the combination of lower extremity musculature blood flow restriction, with slow-walk training, produced significant muscle hypertrophy and strength gains. Abe et al. also studied the effects of six weeks of BFR walk training utilizing older adults, aged 60 to 78, and reported significant improvements in the Timed Up and Go Test (TUG) and the 30-Second Chair Stand Test (30-sCST) without any adverse effects to the training. The safety of utilizing BFR with subjects with pathology was investigated by Mattar et al. They concluded that BFR training is safe and effective in improving strength, function, muscle mass, and the quality of life for older patients with polymyositis (PM) and dermatomyositis (DM), which helped verify the safe use of BFR with patients with varied neurological disease states. Similar to PD, these are neurodegenerative diseases, which lead to decreased muscle strength and overall weakness.

The purpose of the study was to determine the effects of BFR on a recreationally active person with PD in regards to functional improvements and safety. Previous research has shown the positive effects of BFR therapy during gait training on healthy young
and older adults. However, to the best of the authors' knowledge, there is no research examining the effects of BFR gait training on persons with PD. The hypothesis was that this type of training will demonstrate improvements in strength, motor function, gait and endurance, while decreasing symptoms associated with RLS in a subject with PD.

**METHODS**

**Subject:** This study was organized and conducted at the Adele Smither's Parkinson's Disease Treatment Center at W. Kenneth Riland Academic Health Center of the New York Institute of Technology. Inclusion criteria included: (1) a diagnosis of PD by a licensed neurologist (2) a level 2 or 3 on the Hoehn and Yahr scale (3) ability to ambulate on a treadmill (4) overall good health and recreationally active (5) RLS as verified by the RLS Scale (6) score between 1.0 and 1.2 on the Ankle-Brachial Index Scale for peripheral arterial disease. Exclusion criteria included: (1) history of pulmonary disease, heart disease, pneumonia, hypertension, or stroke (2) fall in the prior six months (3) current or former smoker (4) history of deep vein thrombosis, diabetes, intermittent claudication, peripheral vascular disease and peripheral arterial disease. A subject was identified and informed of the procedures of the study and signed a written consent in order to participate in the study. All procedures of the investigation were conducted in accordance with the Helsinki Declaration of 1975. The consent form and the study were approved by the Institutional Review Board of New York Institute of Technology.

The subject in this single-subject design study was a 65-year-old man (height-172.7 cm, weight-78.6 kg, BMI -26.3) who was diagnosed with PD for the past seven years. His United Parkinson's Disease Rating Motor Function Score (MDS-UPDRS III) was a 32, and he was measured as a 2 on the Hoehn and Yahr scale. His Parkinson's medications included artane, azilect, carbidopa/levodopa, rasagiline, and ropinirole. The subject also took a multivitamin daily and CoQ10. He took his medications three times daily and was compliant. The subject's chief symptoms included: shuffling gait pattern, difficulty getting up from a chair, restless leg discomfort, slowness of movement, and difficulty with balance. The subject was a recreational boxer and his chief complaint was that he could not exercise at the level he would like to, due to the rigidity of his disease and he felt his activity level had decreased. He has a history of a partial tear of the left medial meniscus and partial tear of the right Achilles tendon which he had treated successfully with physical therapy in August of 2015. His previous orthopedic injuries did not interfere with the BFR training. The subject was instructed to continue with his daily functional activities and typical exercise regime during both B and A phases, which included participation in boxing classes, one hour 2-3 x/week and independent static stretching activities.

**Study Design:** The study research design was a single subject B-A design, due to subject's time constraints and eagerness to begin the study, the original A-B-A design was changed into a B-A design. The original baseline phase consisted of one session and was concluded after the following outcome measures which reflect functional mobility, gait speed and quality of life were tested. They included the Timed Up and Go Test (TUG), 6-Minute Walk Test (6MWT), RLS Questionnaire, and the 30-Second Chair Stand Test (30-sCST). The B phase included six weeks of intervention and the A phase followed by four weeks of no intervention. The subject was familiarized with the treadmill parameters and the lower extremity BFR cuffs prior to the study. The subject was supervised while walking on an H/P/ Cosmos® treadmill (H/P Cosmos Sports & Medical GMBH, Nussdorf, Germany) at his regular duration and intensity, while vital signs and Borg Scale of Perceived Exertion (RPE) were assessed. After the baseline phase, the subject engaged in lower extremity BFR gait training following Abe’s protocol for KAATSU Walk Training, for the six-week intervention phase (phase B). The subject engaged in BFR training three times a week in the morning hours on nonconsecutive days, under the supervision of the research group. Vital signs and Rating of Perceived Exertion (RPE) measurements were taken pre-, during, and post intervention. Heart rate was taken manually pre- and post-intervention using the dorsalis pedis pulse, while the subject was seated five minutes before intervention and five minutes after intervention. During the intervention, heart
rate was assessed using the radial pulse with a Garmin fitness tracker watch (Garmin Ltd., Olathe, KS) on the subject's right wrist, and at the subject's substernal region with a Polar heart rate sensor (Polar Electro Inc., Lake Success, NY). Blood pressure (BP) was taken manually on the subject's left arm. These measurements were taken during a one-minute rest period between each of the two-minute exercise bouts, where the BFR cuffs were deflated and the subject stopped walking. During the study, the subject's vital signs were monitored, as well as episodes of nausea, shortness of breath, or any other signs of discomfort.

**Outcome Measures:** During the intervention (phase B), the outcomes measures were taken at Day one, and at the end of weeks two, four, and six. The outcome measures were taken again at the end of weeks eight and 10 of the baseline phase (phase A). The TUG measures the time it takes for the subject to stand from a chair without the use of his/her arms, walk three meters, turn around, walk back to the chair and return to the seated position. The 30-sCST requires the subject to stand and sit from a chair as many times as possible in 30 seconds. Abe et al. utilized the TUG and 30-sCST as measures of functional abilities. The 6MWT measures the distance the subject can walk over a total of six minutes on a hard, flat surface. The goal for the subject was to walk as far as possible in six minutes. The subject was allowed to self-pace and rest as needed as they traverse back and forth along a marked walkway. The RLS Rating Scale consists of 10 questions that assist in measuring the effects of restless leg syndrome on the subject's quality of life and has been validated by Walters et al.

**Intervention:** The intervention (phase B) followed Abe's BFR walk-training protocol, which consisted of five, two-minute bouts of treadmill walking with a one minute rest between each trial. The subject walked on the treadmill at zero grade incline and a speed of 50 meters/min throughout the intervention. The subject warmed-up each session by walking for two minutes on the treadmill without BFR. The lower extremity thigh blood pressure cuffs (Hokanson, Bellevue, WA) for the BFR training were introduced and placed on each upper thigh after the warm-up period and pumped to the designated pressure each time. The intervention phase began with the lower extremity blood pressure cuff pumped to a pressure of 120 mmHg. This pressure was chosen because it was the participant's systolic blood pressure, which is in alignment with the guidelines in Abe et al. The cuff pressure was incrementally increased by 20 mmHg every two weeks, as per the subject's tolerance level. As this intervention is the first of its kind for the Parkinson’s population, associated impairments of PD were highly considered when determining the appropriate starting pressure of the cuff. The final pressure reached 160 mmHg by the end of week six. The same outcome measures that were used during the intervention (phase B), were measured throughout the post-intervention (phase A). Post-intervention data collection took place over four weeks after the intervention was concluded. The study was completed at week 10.

**Statistical Analysis:** Visual analysis was utilized to analyze the data because is used most often and is intuitively meaningful according to Portney et al. Comparisons were made between the two adjacent phases based on these three characteristics of the data: level, trend, and slope.

**RESULTS**

Table 1 summarizes all the outcome measure scores from week zero to the end of week 10. Table 2 contains weekly values of average heart rate (HR), peak blood pressure (BP), and peak RPE from the beginning of the study, to the end of phase B, the intervention phase during week six. Figures 1 through 4 illustrate the results of the outcome measures from the beginning of the study to the end at week 10. Figure 1 demonstrates the changes in TUG scores. The level, trend, and slope of Figure 1 is decelerating in phase B representing an improvement in the TUG time while phase A illustrates an accelerating level, trend and slope showing a gradual increase in the TUG time. Figure 1 also displays the fastest time of six seconds, observed after weeks four, six, and eight. Figure 2 presents the changes in 6MWT distance. The level, trend, and slope of Figure 2 is accelerating in phase B representing an improvement in the 6MWT distance time while phase A depicts an decelerating level, trend and slope showing a gradual decrease in the 6MWT distance.
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**Figure 2** also demonstrates the furthest distance walked was 1899.76 feet, observed after week four. **Figure 3** summarizes the 30-sCST results. The level, trend, and slope of **Figure 3** is accelerating in phase B representing an improvement in the 30-sCST results while phase A depicts a decelerating level, trend and slope showing a gradual decrease in the 30-sCST results. **Figure 3** also displays the highest score of 20 repetitions observed after week six and eight. **Figure 4** represents the changes in the RLS questionnaire. The level, trend, and slope of **Figure 4** is decelerating in phase B depicting an improvement in the RLS symptoms while phase A illustrates an accelerating level, trend and slope representing a gradual increase in the RLS symptoms. **Figure 4** also displays the lowest score of 6 (mild symptoms), which was measured after weeks six and eight.

**DISCUSSION**

The purpose of this study was to investigate the effects and safety of lower extremity BFR training on a recreationally active person with PD. BFR training during treadmill walking has previously demonstrated to improve muscle strength and functional abilities in healthy older adults.13 This was the
first study to investigate the safety of utilizing BFR training on a recreationally active person with PD according to a thorough review of the literature. The subject did not experience any adverse effects and he repeatedly stated he enjoyed the training. This is in agreement with Abe et al.\textsuperscript{13} and Matter et al.\textsuperscript{9} who also did not experience any adverse effects with healthy older adults and subjects with a pathology during BFR training respectively. Visual analysis of the data demonstrated that the subject's scores on all outcome measures improved throughout the six-week intervention phase (B) and regressed after four weeks of the post-intervention phase (A).

The improvement in the subject's RLS from moderate to mild was a significant finding, which demonstrated that the subject experienced some relief from those symptoms due to BFR training. RLS was one of his major complaints, interfering with his quality of sleep and life as verified by the RLS questionnaire. He had been taking ropinirole for the relief of his RLS. His score at baseline was a 15 (moderate symptoms), which according to Klingehoefer et al. is the score that requires pharmacological treatment.\textsuperscript{17} Following six weeks of BFR his score decreased to a 6 (mild symptoms), while his score did increase up to an 8 (mild symptoms) after the BFR phase. The addition of the BFR with ropinirole appears to be effective with reducing his RLS symptoms. The subject was very pleased with the improvement with his RLS symptoms. Massaging or rubbing of the affected limbs and physical exercise may benefit RLS according to Klingehoefer et al.\textsuperscript{17} Since he was physically active and maintained his usual exercise activities besides the pharmacological treatment of ropinirole, the addition of the BFR may have contributed to the
reduction in his symptoms. The physiological mechanism behind providing relief of his RLS symptoms may have been the pressure on the affected limbs provided by the BFR training. Further research into this phenomenon is warranted. Although the subject stated his legs were fatigued from the intervention, it did not have any impact on his boxing routine. The subject reported that he felt his performance improved in boxing.

The improvements in the TUG and 30-sCST were similar to the results of Abe et al.13 These results suggest that BFR training generates beneficial outcomes in the areas tested with a positive retention period of approximately two weeks. The TUG is highly correlated with functional mobility, gait speed and falls in older adults and has high test-retest reliability in the PD population.18 His TUG time decreased from 9.0 seconds to 6.0 seconds following BFR training. Both times were below the 11.5 cut off score for to discriminate between patients with PD who have fallen and not fallen.18 His improvement of three seconds in the TUG was close to the minimal detectable change of 3.5 seconds for people with PD as reported by Huang et al.19 The 30-sCST is useful for detecting changes in functional gait and mobility in PD patients according to Petersen et al.20 His 30-sCST improved from a 14 to a high of 20 repetitions after six weeks of BFR training and declined to 17 after the intervention was stopped. His initial score of 14 was within the norm and his improvement to 20 surpassed the minimal detectable difference of 3.3 repetitions as reported by Petersen et al.20 The 6MWT provides a measure of walking capacity in PD patients.14 Our subject improved from an initial distance of 1372.45 ft. to 1899.76 ft. after four weeks of BFR training before decreasing to 1574.80 ft. four weeks after the intervention ended. His initial distance was below the mean of 1790.03 ft. for a PD patient with a Hoehn and Yahr score of 2 as reported by Shenkman et al.21

Resistance training and endurance training have been shown to improve neuromuscular function, bradykinesia, and postural instability in patients with PD.9 The improvements in cardiorespiratory capacity and endurance is observed to enhance the efficacy of levodopa, which improves gait abnormalities and motor control as seen with persons with PD.22,23 Archer et al.24 have shown that moderate to high-intensity training (65-80% of 1-RM) results in greater quality of life, less fatigue and disorder severity in patients with PD. The results of this study may add BFR training to the available exercise options for the PD population.

The strengths of the study include: subject compliance, consistency of the intervention schedule per week, and the functional outcome measures tested are widely used by rehabilitation specialists for people with PD. The study had several limitations: which include the inherent flaw of the single subject design of its limited external validity or lack of generalizibility.16 The other limitations include the one day of baseline data because the subject wanted to start the intervention phase as soon as possible because of his time constraints and his eagerness to start the intervention which changed the design from a A-B-A to a B-A design. The length of the phases did not allow for sufficient data points to calculate a correlation line, utilize the two standard deviation band method or the C-statistic.16 Despite these limitations, the positive results on the effects of BFR training with a subject with PD support the need for continued research for this type of exercise. Future studies should replicate this single subject design study with longer phases that would allow for more data points. The use of randomized clinical trials is also warranted that will provide the strongest evidence for the effectiveness of BFR training with the PD population.

CONCLUSIONS
This was the first study to observe the effects of BFR walk training as an effective and safe intervention for a recreationally active person with PD. BFR treadmill training, as a low-intensity intervention, was tolerated well and without any adverse effects. The subject demonstrated improvements in the TUG, 6MWT, RLS, and the 30sCST over the six-week intervention phase with regression noted four weeks after the intervention concluded. BFR treadmill training can be safely added to the exercise regime for a recreationally active person with PD who wishes to maintain his ability to remain recreationally active. Future research is warranted on the use of BFR training as an effective intervention to reduce the debilitating effects of PD.
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ABSTRACT

Background and Purpose: Differentiating between cervical nerve root and peripheral nerve injuries can be challenging. A phenomenon known as double crush syndrome may increase the susceptibility to injury and symptoms at other locations along the course of the nerve. The purpose of this case report is to describe the physical therapy differential diagnosis and management of a cyclist with upper extremity pain, weakness, and paresthesia.

Case Description: The subject was referred to physical therapy with a diagnosis of cervical disc disease. His chief complaints were chronic neck and right shoulder pain as well as a recent onset of right hand numbness and weakness following 100-mile bike ride one month prior. Diagnostic imaging revealed multi-level degenerative changes of the cervical spine. Initial electromyography and nerve conduction studies (EMG/NCS) indicated right ulnar neuropathy at the elbow. The ultimate incorporation of ulnar nerve mobilizations in various positions immediately decreased symptoms. In light of the subject's improvement after ulnar nerve mobilizations, imaging findings, and EMG/NCS findings, the subject's presentation was consistent with a double crush syndrome with C8 nerve root compression and distal ulnar nerve compression at the elbow.

Outcomes: The subject demonstrated full resolution of all symptoms, 0% disability on the Neck Disability Index, 8.3% disability of the Disabilities of the Arm, Shoulder, and Hand questionnaire, normal EMG/NCS findings, and unrestricted return to work and endurance cycling at three months and maintained at one year. He did not require hand surgery.

Discussion: This case report highlights the importance of continual clinical re-examination and re-assessment with ancillary diagnostic testing, especially if chosen interventions are not eliciting desired responses. The identification of key risk factors, such as occupation and recreational activities is imperative in achieving the most efficacious clinical treatment. In this case, the recognition of a double crush syndrome assisted in optimizing the physical therapy plan of care and the subject ultimately achieving full recovery.

Level of evidence: Level 4

Key words: Double crush syndrome, nerve root, radiculopathy, ulnar nerve upper limb tension
BACKGROUND AND PURPOSE
The peripheral nervous system is composed of a continuum of dynamic neural structures that must withstand a variety of mechanical actions and physiological adaptations to facilitate normal mobility among and across joints, muscles, and connective tissues. Neurodynamics, first described in 1995 by Shacklock et al, broadly encompasses these interdependent mechanical and physiological changes that occur with both normal and pathological processes related to nerve elongation, angulation, compression, and sliding, as well as local histological and vascular responses that may occur. Peripheral nerve compression and entrapment commonly presents clinically with sensory deficits within the affected nerve distribution, followed by muscle weakness. Additionally, pain at the entrapment site is not uncommon. Neurophysiologic abnormalities can be detected using electromyography and nerve conduction studies (EMG/NCS), however diagnostic testing alone is not sufficient in diagnosis of peripheral neuropathies and often is limited in detecting acute neural changes or mild radiculopathy. In the upper extremity, compression of the median nerve at the wrist is the most common site of entrapment affecting approximately 1-7% of the general population. Ulnar nerve entrapment most commonly occurs at the cubital tunnel at the elbow, whereas radial nerve compression is extremely rare. In addition to peripheral mononeuropathies, Upton and McComas introduced the concept of a condition called double crush syndrome, and proposed that neural impairments at a more proximal location increase the susceptibility to injury and symptoms at more distal locations along the course of the nerve due to impaired axial flow. It has also been hypothesized that a distal site of compression could make the more proximal nerve susceptible to secondary compression, described as a reverse double crush syndrome. With the potential to occur at points anywhere along the course of the nerve, one must consider the presence of double crush syndrome in relation to evaluation of patients with diagnoses of cervical radiculopathies and upper extremity neuropathies. One must be aware of the variability in explanations for the mechanisms associated with double crush syndrome. In 2011, a Delphi study by Schmid et al explored the views of experts in the field and concluded that a consensus agreement has not yet been reached regarding the mechanisms leading to double crush syndrome. Although compression of the ulnar nerve at Guyon's canal among cyclists is well documented, cyclists with clinical diagnoses of ulnar neuropathy may also present with proximal dysfunction suggesting an increased prevalence of double crush syndrome in this population.

Upper extremity pain, numbness, and weakness can be challenging to treat due to many possible diagnoses and sources of tissue involvement. Careful history taking and clinical examination is essential to understanding the site of compromise in order to properly treat the underlying cause. Neuroimaging and neurophysiological studies are often used to confirm or refute a clinical diagnosis once established, however, are not always needed in treatment of upper quarter neurological symptoms. The purpose of this case report is to describe the physical therapy differential diagnosis and management of a cyclist with upper extremity pain, weakness, and paresthesia.

CASE DESCRIPTION: SUBJECT HISTORY AND SYSTEMS REVIEW (FIGURE 1)
The subject was a right-handed 54-year-old Caucasian male referred to an outpatient, sports focused physical therapy clinic. He had a medical diagnosis of cervical disc disease and a referral with specific instructions for use of cervical traction. He was a practicing dentist and an avid recreational road cyclist, riding approximately 100-200 miles weekly. He also participated in weight training with a personal trainer twice a week.

The subject consented to physical therapy treatment. He presented with a chronic history of right cervicothoracic paraspinal pain, right periscapular pain, and associated muscle tightness in these regions. These complaints had intensified approximately four weeks prior, following an unremarkable 100-mile bike ride. In addition to an exacerbation of these preexisting symptoms, the subject also complained of a concurrent, novel onset of right hand numbness on the dorsal and palmar surfaces of his right fifth digit and medial one-half of his right fourth digit. The subject described these distal symptoms as constant and unchanging regardless of activity or...
The subject was an otherwise healthy adult male with a significant medical history of osteoarthritis in bilateral hands, which he managed with over-the-counter nonsteroidal anti-inflammatory drugs (NSAIDs) to decrease pain in the evenings. He was currently taking ibuprofen 400-800mg as needed. He denied any preexisting numbness and/or tingling, deficits in hand strength, or difficulty performing work duties prior to the present complaints.

**Diagnostic Testing**

Prior to his initial physical therapy examination, the subject had obtained radiographs (Figure 2) and magnetic resonance imaging (MRI) (Figure 3) of his cervical spine ordered by his referring physician. The radiologist’s reports of these tests indicated multilevel degenerative changes and bilateral neural foraminal narrowing C4-C5/C5-C6, as well as disc osteophytes at C5-6/C6-7. The subject was also referred to a hand surgeon who ordered EMG/NCS which was scheduled for one week following the initial physical therapy evaluation.

**CLINICAL IMPRESSION #1**

The subject’s primary problem involved right upper extremity pain, paresthesia, and weakness which were affecting his activities of daily living, job duties, and athletic participation. Information gathered during the history and systems review led to a differential diagnosis of cervical nerve root radiculopathy versus distal ulnar nerve involvement. Review of EMG/NCS results was identified as potentially useful in assisting to clarify the potential pathology and tissue structures involved and thus the subject was asked to bring those results in for review once the

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**Figure 1. Time Line from initiation of symptoms to one-year follow-up.**

- September: Initiation of symptoms after 100 mile bike ride
- October 6th: Initial PT Evaluation
- October 13th: Hand Surgeon: EMG/NCV Testing
- October 20th: Incorporation of Ulnar Nerve Mobilizations with associated reduction in symptoms
- December 10th: Bike Fit & Recreational Cycling
- December 30th: Resolution of symptoms & Discontinue episode of care

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The subject continued to work as a dentist, but cited increased difficulty secondary to decreased strength in his right hand. Finally, the subject reported a long-standing history of bilateral hand and finger osteoarthritis.

Treatment over the four weeks prior to the initiation of physical therapy included massage therapy and chiropractic treatments, which had reduced his right sided cervical and thoracic pain, but had no effect on his right hand and elbow symptoms. He reported a long history (over several years and at varying frequencies) of massage and chiropractic treatment for his cervical and thoracic complaints focusing on cervical adjustments and massage. The subject’s goals were to eliminate his hand numbness and weakness so he could perform his job duties as a dentist, return to cycling, and perform weight training exercises without restriction.

A review of systems revealed no complaints of constitutional symptoms, changes in bowel or bladder habits, weight fluctuations, or changes in appetite.
testing had been completed. Planning for the examination, included standard cervical clearing tests, basic range of motion, strength (myotomal), and sensation (dermatomal) assessments for the cervical spine would be performed. In addition, the test item cluster for cervical radiculopathy and Upper Limb Neural Tensioning Testing would be performed to discern the likelihood of cervical radiculopathy versus peripheral nerve involvement. Understanding the differential diagnosis of these conditions is essential in identifying the best treatment options and plan of care. This is particularly important with at risk populations for cervical radiculopathy and/or peripheral neuropathy such as dentists and cyclists.13,14,20-22

EXAMINATION #1 (TABLES 1 AND 2)

Upon observation, the subject presented with increased kyphosis in the upper and mid thoracic spine and a forward head posture. Gross observation and examination of the cervical spine revealed decreased active end range of motion (ROM) with cervical flexion and right cervical rotation (due to time constraints goniometric or inclinometer measurements were not performed). For cervical flexion, the subject was unable to touch his chin to his chest, but this was not limited by pain nor did it

Figure 2. Frontal and sagittal plane cervical radiographs. The radiologist’s official findings were disc space narrowing present at C3-4, C5-6, and C6-7, facet arthropathy and uncovertebral overgrowth present at C4-C5 and C5-C6 bilaterally, as well as bilateral neural foraminal narrowing.

Figure 3. Sagittal T2 weight Magnetic Resonance Image (MRI) without contrast. The radiologist’s official findings from the MRI were C3-C4 uncovertebral joint hypertrophy and facet arthropathy with resultant mild bi-foraminal stenosis, C4-5 evidence of mild right neural foraminal stenosis, C5-6 a broad disc-osteophyte complex with resultant mild degree of central canal stenosis with no cord compression, C6-7 a broad disc-osteophyte complex with resultant mild central canal stenosis with no compression, C7-T1 no significant disc protrusion evident.
artery testing for vertebral artery insufficiency [Sensitivity: 0.00 to 0.31; Specificity: 0.39 to 0.86; +Likelihood Ratio: 0.00 to 0.59; -Likelihood Ratio: 1.16 to 2.30],25,26 axial cervical compression,19,27 cervical quadrant testing (“Spurling Test”) [Kappa: 0.40 to 0.77; Sensitivity: 0.40 to 0.60; Specificity: 0.86 to 1.0; +Likelihood Ratio: 3.5; -Likelihood Ratio: 0.58],19,28 cervical distraction [Kappa: 0.50 to 0.88; Sensitivity: 0.40 to 0.50; Specificity: 0.86 to 1.0; +Likelihood Ratio: 4.4; -Likelihood Ratio: 0.62],19,27,28 and Adson’s test [Specificity: 0.18 to 0.87; Sensitivity: 0.94; Positive Predictive Value: 0.85; Negative Predictive Value: 0.72].13,29 Performance of Roos test for thoracic outlet syndrome [Sensitivity: 0.84; Specificity: 0.30; Positive Predictive Value: 0.68; Negative Predictive Value: 0.50]13,29 was negative for changes in sensation or provocation of symptoms, but continued performance resulted in decreased ability to actively extend and open and close his right hand when compared to his left. The subject had a negative Hoffmann’s sign [Sensitivity: 0.58; Specificity: 0.78].28,30 Testing of ulnar, radial, and median nerves utilizing Tinel’s sign [Sensitivity: 0.50; Specificity: 0.77] at the elbow and wrist (Guyon’s canal and Carpal tunnel) failed to produce symptoms.27,31 Passive Upper Limb Neural Tensioning Test (Upper Limb Tension Test A or ULTT-A) [Kappa: 0.54 to 0.76; Sensitivity: 0.97; Specificity: 0.22]19,32 and for ulnar nerve (Ulnar Upper Limb Tension Test or Ulnar ULTT ) [Kappa: 0.36]32 failed to elicit symptoms as well (Table 2).33 At this point the subject did not demonstrate any positive tests for the test item cluster for cervical radiculopathy.19

The subject was initially administered the Neck Disability Index (NDI) by the clinic’s front desk personnel as his referral indicated a cervical problem. Depending upon the associated neck condition, the NDI has adequate to high ICC values (ICC: 0.50 to 0.96).24,33 Minimally clinically important difference

### Table 1. Patient Reported Outcomes

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Initial Visit</th>
<th>Visit 8</th>
<th>Visits 12 &amp; 13</th>
</tr>
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<tbody>
<tr>
<td>Global Rating of Function</td>
<td>Question not asked</td>
<td>85%</td>
<td>95%</td>
</tr>
<tr>
<td>Perception of Right Hand Numbness</td>
<td>Constant</td>
<td>90% reduced</td>
<td>100% reduced</td>
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<tr>
<td>NDI</td>
<td>12%</td>
<td>Not Administered</td>
<td>0%</td>
</tr>
<tr>
<td>DASH</td>
<td>Not Administered</td>
<td>Not Administered</td>
<td>8.3%</td>
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</tbody>
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NDI = Neck Disability Index
DASH = Disabilities of the Arm, Shoulder and Hand
re-examination and re-evaluation of subject symptoms throughout treatment. Evaluation of the EMG/NCS would provide potentially valuable information pertaining to the subject’s symptoms and related interventions. The initial physical therapy sessions were planned for twice a week to focus on manual techniques and postural cueing with continual re-evaluation of symptoms and progress. In addition, formal testing of the periscapular muscles would be performed to further evaluate the potential impact of scapular and postural control on the subject’s symptoms. Formal re-evaluation of initial testing procedures was planned after four weeks of treatment.

<table>
<thead>
<tr>
<th>Table 2. Clinical Examination Findings</th>
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<tbody>
<tr>
<td>Measurement</td>
</tr>
<tr>
<td>Vertebal Artery Insufficiency Testing</td>
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<tr>
<td></td>
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<tr>
<td>Right Cervical Rotation</td>
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<td>Cervical Compression</td>
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<td>Cervical Distraction</td>
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<td>Spurling Test</td>
</tr>
<tr>
<td>Thoracic Outlet Testing and Neurologic Testing</td>
</tr>
<tr>
<td>Adson’s Test</td>
</tr>
<tr>
<td>Roos Test</td>
</tr>
<tr>
<td>Light Touch Sensation</td>
</tr>
<tr>
<td>ULNTT</td>
</tr>
<tr>
<td>Radial</td>
</tr>
<tr>
<td>Media</td>
</tr>
<tr>
<td>Tinel’s Sign</td>
</tr>
<tr>
<td>Hoffman’s Sign</td>
</tr>
<tr>
<td>Strength Testing</td>
</tr>
<tr>
<td>Finger abduction/adduction (MMT)</td>
</tr>
<tr>
<td>Thumb abduction strength (MMT)</td>
</tr>
<tr>
<td>Grip Strength (kg)</td>
</tr>
<tr>
<td>P = Positive</td>
</tr>
<tr>
<td>N = Negative</td>
</tr>
<tr>
<td>NT = Not Tested</td>
</tr>
<tr>
<td>ULNTT = Upper Limb Neural Tensioning Testing</td>
</tr>
<tr>
<td>*Reported decreased ability to actively extend and open and close his right hand when compared to his left</td>
</tr>
<tr>
<td>†Decreased sensation to light touch at the dorsal and palmar surfaces of the right fifth digit, medial one-half of the right fourth digit in ulnar nerve distribution</td>
</tr>
</tbody>
</table>

The clinical examination did not confirm the presence of cervical radiculopathy or peripheral nerve involvement. Additional clinical examination led to a working diagnosis of decreased lower cervical spine mobility and poor cervical and upper extremity postural control and awareness with consideration of potential of cervical nerve root radiculopathy and secondary distal ulnar nerve involvement. However, the likelihood of cervical radiculopathy could be ruled out with 97% confidence secondary to a negative finding on the ULTT-A test of the cervical radiculopathy test item cluster. The decision was made to initiate treatment focused on the primary impairments noted above focused on improving spinal mobility. However, the inconclusive clinical examination findings necessitated continual re-examination and re-evaluation of subject symptoms throughout treatment. Evaluation of the EMG/NCS would provide potentially valuable information pertaining to the subject’s symptoms and related interventions. The initial physical therapy sessions were planned for twice a week to focus on manual techniques and postural cueing with continual re-evaluation of symptoms and progress. In addition, formal testing of the periscapular muscles would be performed to further evaluate the potential impact of scapular and postural control on the subject’s symptoms. Formal re-evaluation of initial testing procedures was planned after four weeks of treatment.

CLINICAL IMPRESSION #2
The clinical examination did not confirm the presence of cervical radiculopathy or peripheral nerve involvement. Additional clinical examination led to a working diagnosis of decreased lower cervical spine mobility and poor cervical and upper extremity postural control and awareness with consideration of potential of cervical nerve root radiculopathy and secondary distal ulnar nerve involvement. However, the likelihood of cervical radiculopathy could be ruled out with 97% confidence secondary to a negative finding on the ULTT-A test of the cervical radiculopathy test item cluster. The decision was made to initiate treatment focused on the primary impairments noted above focused on improving spinal mobility. However, the inconclusive clinical examination findings necessitated continual re-examination and re-evaluation of subject symptoms throughout treatment. Evaluation of the EMG/NCS would provide potentially valuable information pertaining to the subject’s symptoms and related interventions. The initial physical therapy sessions were planned for twice a week to focus on manual techniques and postural cueing with continual re-evaluation of symptoms and progress. In addition, formal testing of the periscapular muscles would be performed to further evaluate the potential impact of scapular and postural control on the subject’s symptoms. Formal re-evaluation of initial testing procedures was planned after four weeks of treatment.

INTERVENTION
Initial Plan of Care and Physical Therapy Interventions (Table 3)

Visits 1-4
The discussion of the interventions from visits 1-4 in this case report are to provide a global perspective of the subject’s overall treatment but are not the
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**Table 3. Sequencing and Timeline of Selected Interventions**

<table>
<thead>
<tr>
<th>Interventions</th>
<th>Visits 1-4</th>
<th>Visits 5-8</th>
<th>Visits 9-13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postural Education</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strengthening Ex*</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Soft Tissue Mobilization†</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Mechanical Traction</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cervicothoracic Mobilization‡</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Ulnar Neural Mobilization§</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Periscapular Neuromuscular Control Training¥</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bike Fitting</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

* No changes or improvement in upper extremity symptoms were noted until visit 5 with the initiation of the ulnar nerve mobilizations. The subject reported substantial reduction of elbow symptoms following initiation of these techniques.

* Strengthening exercises focused on the following: deep neck flexors (visits 1-4), periscapular musculature (visits 5-13), hand intrinsics (visits 9-13).

† Soft tissue mobilization techniques used included deep pressure and myofascial trigger point release techniques focused on cervical paraspinals, right upper trapezius, right levator scapulae, right anterior scalene, and right rhomboids.

‡ Mobilizations included C3-C6 side glides, manual cervical distraction, thoracic spine thrust, first rib mobilization.

§ Including prone non-weight bearing exercises progressing to weight bearing and upright exercises using unstable surface and resistance.

The primary focus of this case report (Table 3). Initial interventions (visits 1-4) primarily targeted restoration of normal, symmetrical cervicothoracic joint and soft tissue mobility for improved function with the goal of reducing both cervicothoracic pain and elbow/hand symptoms. More specifically, manual mobilization techniques were utilized and included side glide techniques (grades III and IV) to C3-C6, manual cervical distraction, thoracic spine thrust techniques and first rib mobilizations. Soft tissue mobilization was performed on the cervical paraspinals, right upper trapezius, levator scapulae, and rhomboids employing techniques focused on deep pressure and myofascial trigger point release. Basic scapular retraction and deep cervical flexor endurance exercises were utilized to address poor postural tendencies. In addition, the subject was also educated on postural control and awareness with emphasis on workplace ergonomics and positioning, as the subject reported an increase in symptoms on days in which he saw patients in a clinical setting. During this initial phase of treatment, the subject reported an improvement in periscapular discomfort; however, no change in his distal upper extremity symptoms were reported otherwise. In addition, secondary to several requests from the referring physician, mechanical traction was initiated on the third visit. No changes in symptoms resulted from the mechanical traction, so it was not continued.

Between the second and third physical therapy sessions the EMG/NCS were performed as previously ordered by the hand surgeon (Tables 4, 5, and 6). The testing physician's impression was an “abnormal study” with “findings and clinical picture [being] most consistent with a right mild axonal ulnar neuropathy at the elbow” with “no evidence of cervical radiculopathy.” Following the EMG/NCS, the medical recommendation by the hand surgeon was for a nerve release at the elbow. However, the subject declined this intervention and opted to continue physical therapy. A follow-up EMG/NCS was scheduled approximately six weeks later.

**Visits 5-8**

Secondary to minimal changes in distal UE symptoms during visits 1-4, reassessment using the Ulnar ULTT was performed at visit 5. At this point, repeated performance of this test reproduced symptoms at the elbow and hand in contrast to the subject's initial physical therapy visit. Based on the provocation with this testing at this time, ulnar nerve glides directed at neural mobilization and decreasing the mechanosensitivity of the ulnar nerve and surrounding tissues was initiated. Passive and active mobilization of the right ulnar nerve was performed at the point of symptom provocation and reduction, with the subject in supine. The shoulder was externally rotated and abducted to a point of symptom provocation. Nerve
Selected Electromyography study results from available physician reports dated on October 13th and November 23rd. Dec = Decreased; Insert = Insertional Activity; Fibs = Fibrillating Potentials; MUP = Motor Unit Potential; NR = Not reported; Nlm = Normal; Poly = Polyphasic Potentials; PSW = Positive Sharp Waves; Recruit = Recruitment; Spont = Spontaneous Activity.

**Examination Findings:***
- **October 13th:** Electromyography of the right upper limb is significant only for 1+ positive sharp waves and fibrillations in the right ulnar innervated hand muscles.
- **November 23rd:** No abnormalities in any of the areas tested in the right upper limb and corresponding perispinal muscles with no evidence of cervical radiculopathy or brachial plexopathy. Normal EMG/NCS of the right upper limb. No evidence of ulnar or entrapment neuropathy.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Nerve</th>
<th>Root</th>
<th>Fibs</th>
<th>PSW</th>
<th>MUP</th>
<th>Insert</th>
<th>Spont</th>
<th>Poly</th>
<th>Recruit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Dorsal</td>
<td>Ulnar</td>
<td>C8-T1</td>
<td>1+</td>
<td>Nml</td>
<td>NR</td>
<td>NR</td>
<td>0</td>
<td>Dec</td>
<td>NR</td>
</tr>
<tr>
<td>Biceps</td>
<td>Musculocutaneous</td>
<td>C5-6</td>
<td>Nmnl</td>
<td>Nmnl</td>
<td>NR</td>
<td>NR</td>
<td>0</td>
<td>Nml</td>
<td>NR</td>
</tr>
<tr>
<td>Triceps</td>
<td>Radial</td>
<td>C6-7</td>
<td>Nml</td>
<td>Nml</td>
<td>NR</td>
<td>NR</td>
<td>0</td>
<td>Nml</td>
<td>NR</td>
</tr>
<tr>
<td>Pronator Teres</td>
<td>Median</td>
<td>C6-7</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>Nml</td>
<td>NR</td>
</tr>
<tr>
<td>Deltoid</td>
<td>Axillary</td>
<td>C5-6</td>
<td>Nml</td>
<td>Nml</td>
<td>NR</td>
<td>NR</td>
<td>0</td>
<td>Nml</td>
<td>NR</td>
</tr>
<tr>
<td>Paraspinals Rami</td>
<td>Ulnar</td>
<td>C8</td>
<td>Nml</td>
<td>Nml</td>
<td>NR</td>
<td>NR</td>
<td>0</td>
<td>Nml</td>
<td>NR</td>
</tr>
<tr>
<td>Flexor Carpi Ulnaris</td>
<td>Ulnar</td>
<td>C8</td>
<td>Nml</td>
<td>Nml</td>
<td>NR</td>
<td>NR</td>
<td>0</td>
<td>Nml</td>
<td>NR</td>
</tr>
<tr>
<td>Extensor Indicis</td>
<td>Radial</td>
<td>C7-8</td>
<td>Nml</td>
<td>Nml</td>
<td>NR</td>
<td>NR</td>
<td>0</td>
<td>Nml</td>
<td>NR</td>
</tr>
</tbody>
</table>

Table 4. Electromyography Studies

Table 5. Nerve Conduction Studies - Motor

<table>
<thead>
<tr>
<th>Right Median Motor (APB)</th>
<th>Norm Onset (ms)</th>
<th>Norm Velocity (m/s)</th>
<th>October 13th</th>
<th>November 23rd</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Onset (ms)</td>
<td>Velocity (m/s)</td>
<td>Onset (ms)</td>
<td>Velocity (m/s)</td>
</tr>
<tr>
<td>Wrist</td>
<td>4.3</td>
<td>45</td>
<td>3.6</td>
<td>51.9</td>
</tr>
<tr>
<td>Elbow</td>
<td>8.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbow – Wrist</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Ulnar Motor (ADM)</td>
<td>Onset (ms)</td>
<td>Velocity (m/s)</td>
<td>Onset (ms)</td>
<td>Velocity (m/s)</td>
</tr>
<tr>
<td>Wrist</td>
<td>4.0</td>
<td>53</td>
<td>2.7</td>
<td>2.6</td>
</tr>
<tr>
<td>Below Elbow</td>
<td>53</td>
<td>6.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Above Elbow</td>
<td>8.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below Elbow – Wrist</td>
<td>53.8</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Above Elbow – Below Elbow</td>
<td>64.3</td>
<td>61</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ADM = Abductor Digiti Minimi; APB = Abductor Pollicis Brevis; Norm = Normative; ms = milliseconds; m/s = meters per second

**Examination Findings:***
- **October 13th:** The absence of focal slowing on nerve conduction studies suggest the absence of significant demyelination.
- **November 23rd:** Normal EMG/NCS of the right upper limb. No evidence of ulnar or entrapment neuropathy.

Table 6. Nerve Conduction Studies - Sensory Left/Right Comparison

<table>
<thead>
<tr>
<th>Dorsal Cutaneous Sensory</th>
<th>October 13th</th>
<th>November 23rd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Latency (ms)</td>
<td>3.5</td>
<td>3.6</td>
</tr>
<tr>
<td>Right Latency (ms)</td>
<td>3.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Left Amplitude (µV)</td>
<td>43.0</td>
<td>22.0</td>
</tr>
<tr>
<td>Right Amplitude (µV)</td>
<td>20</td>
<td>NR</td>
</tr>
</tbody>
</table>

ADM = Abductor Digiti Minimi, APB = Abductor Pollicis Brevis, Norm = Normative. Normal Sensory Amplitude = > 20µV; ms = milliseconds; m/s = meters per second; µV = microvolts; NR = Not reported

**Examination Findings:***
- **October 13th:** Normal radial, median, and ulnar sensory distal latencies are normal with normal amplitudes. Normal left ulnar sensory distal latency with normal amplitude. Normal left dorsal ulnar cutaneous distal latency with normal amplitude. Normal right dorsal ulnar cutaneous distal latency with relative decrease in amplitude compared to the left.
- **November 23rd:** The right median and ulnar nerve conduction studies within normal limits.
sliding was initiated with concomitant wrist extension and right cervical side-bending followed by wrist flexion and left cervical side-bending. Repetitions were performed until the subject reported a decrease in elbow symptoms during this technique (Table 3). As symptoms at the elbow decreased, mobilization of the ulnar nerve was progressed by adding elbow flexion and extension. Elbow flexion occurred with wrist extension and right cervical side-bending, and elbow extension occurred with wrist flexion and left cervical side-bending. Repetitions were again performed until the subject reported a reduction in symptoms with this neural sliding technique. The subject was subsequently educated on independent performance of seated active right ulnar nerve mobilization techniques to be performed at home three to five times daily starting with wrist flexion/extension and cervical side bending as previously described. The subject was instructed to perform as many repetitions as were needed to reduce symptoms, up to 30 times in a row. At the conclusion of this treatment session, for the first time since his initial complaints of right elbow pain he reported a substantial decrease in complaints in right elbow symptoms with right cervical rotation.

Subsequent to the initiation of ulnar nerve mobilization in the clinic and instruction on performance of active ulnar nerve mobilization techniques independently at home, the subject reported continued decrease in elbow symptoms and fluctuating symptoms within the ulnar distribution at his right hand, with periods of significant relief. Treatment continued to focus on ulnar nerve mobility across multiple joints of the neck and upper extremity, guided by provocation or alterations in symptoms. Ulnar nerve glides were progressed in sitting and performed with movement of the wrist, elbow, and shoulder at the same time as the cervical spine as previously described. The focus was movement that ultimately reduced symptoms. Additionally, as an adjunctive intervention, manual grade III and IV joint mobilization of the lower cervical spine, upper thoracic spine, and first rib were continued, focusing on improving joint mobility. At this time, the subject was instructed to continue the performance of ulnar nerve gliding techniques independently and observe any changes in his symptoms with plans to return to physical therapy in 12 days, following a vacation.

Upon return from vacation and reported diligent adherence to his home program, the subject reported a decrease in the frequency and intensity of his neurological symptoms, with distal numbness present approximately 10% of the time, rare occurrences of symptoms at the elbow, yet continued complaints of upper trapezius tightness. Reassessment after eight physical therapy visits over four weeks indicated improved right hand intrinsic strength, subject reported 85% improvement in right hand paresthesia and subjective improvements in grip strength at work as a dentist (Table 1). At the time of re-evaluation, the subject presented with improved symptoms, however, deficits in thoracic and cervical posture persisted. Formal testing of the lower trapezius and rhomboids revealed 4/5 strength with manual muscle testing (MMT).

CLINICAL IMPRESSION #3
Following continued clinical reassessment, symptom improvement following ulnar nerve mobilizations, and the MRI and EMG/NCS results, the diagnosis and assessment was modified to be suspicious of a double crush syndrome with C8 nerve root compression and distal ulnar nerve symptoms and compression at the elbow. Ulnar nerve mobilizations were the primary intervention and focus of treatment and were performed as symptoms continued to decrease. Following visit eight, the frequency of formal physical therapy treatment sessions was decreased secondary to subject improvement, independence with interventions, and the subject traveling.

INTERVENTION
Final Plan of Care and Physical Therapy Interventions (Table 3)

Visits 9-13
Although not the primary focus of this case report, in this final phase of treatment, physical therapy interventions concentrated on supportive activities focused on postural control, endurance, and return to prior level of function, specifically participation at work and return to cycling (Table 3). Visits 9-11 focused primarily on periscapular exercises to promote optimal posture, control, and muscular endurance for his activities of choice (e.g. dentistry and
neck tightness. The subject and therapist agreed that no need for skilled physical therapy intervention remained and that the subject was to return in three weeks for reassessment regarding any change in symptoms or presence of functional limitations. Upon follow-up (visit 13), the subject reported a full return to prior level of function with nearly complete resolution of symptoms.

OUTCOMES

Formal outcome measures were obtained at visits 8 and 13. At visit 8 (4 weeks of treatment) the subject reported that his hand numbness was reduced by 90%, he had 85% overall improvement, and no elbow pain. Objectively he had no elbow symptoms with end range right cervical rotation and increased finger abduction/adduction strength, now graded as a 4/5 with MMT. He also denied exacerbation of symptoms with the ulnar nerve tension test. At visit 13, the subject reported nearly complete resolution of all symptoms with only periodic hand numbness one to two times approximately every two weeks that resolved quickly with his nerve gliding techniques. Further, he had returned to full and unrestricted job duties and continuation of cycling. His follow-up EMG/NCS results indicated as “normal” with “no evidence of ulnar nerve involvement.” During his last visit he scored 0% disability on the NDI and was also administered the Disabilities of the Arm, Shoulder, and Hand (DASH). Depending upon the upper extremity condition, the DASH has adequate to high ICC values (ICC: 0.54 to 0.99), minimally clinically important difference reported from 10 to 10.2 points, and minimal detectable change from 10 to 12.2 points. The subject reported 8.3% disability on the DASH which he attributed to his hand osteoarthritis. The lack of a baseline DASH score does limit the understanding regarding the magnitude of improvement related to this tool and in retrospect this questionnaire should have been administered sooner in the subject’s care. However, considering the low level of disability recorded on the final treatment DASH score, the marked improvement in both the subject’s self-reported symptoms and function, as well as the EMG/NCS results, the lack of baseline DASH score has minimal impact in understanding and appreciating the subject’s overall outcomes and improvement. Finally, at a one-year follow-up the

On visit 12, the subject participated in a static bike fitting assessment by the primary treating physical therapist. This was conducted in order to evaluate his positioning on the bike to potentially decrease stress on the right ulnar nerve and address any faulty posture which may have contributed to his injury, prevent future injury, and to improve performance. It was determined that no specific changes to the bike were warranted during the fitting assessment. However, extensive education was performed during the session. This education was focused on improving the subject’s awareness of his cervical, thoracic, and upper extremity positions in order to minimize sustained forward head posture, limit shoulder protraction, and optimize hand position throughout long rides.

In addition to physical therapy interventions, the subject had resumed participation in personal training sessions 2-3 times weekly and cycling on the weekends. He reported that he was currently free of all symptoms 95% of the time and was able to self-manage his symptoms when present through the performance of ulnar nerve mobilization techniques. He continued to receive regular chiropractic manipulations and massage, as he had done prior to this episode of symptoms, as he felt those treatments were helpful in managing his upper back and
subject reported no symptoms and continued work as a dentist as well as cycling.

**DISCUSSION**

In this case report, a subject with substantial risk factors for double crush syndrome including long distance road cycling and working full time as a dentist was described with a primary focus on illustrating his outcomes following ulnar nerve mobilizations. EMG/NCS confirmed the diagnosis of ulnar nerve entrapment at the elbow. Even though EMG/NCS was negative for cervical radiculopathy, MRI findings were indicative of multilevel cervical foraminal narrowing. However, narrowing at the C7-T1 segment was not shown via MRI. Further, although the subject did demonstrate decreased cervical rotation and flexion, he did not present with the a positive test item cluster (ULTT-A, distraction test, Spurling test) indicative of cervical radiculopathy.19 Notably, Wainner et al19 evaluated the diagnostic accuracy of cervical flexion and rotation range of motion related to cervical radiculopathy and showed that less that less than 55° of cervical flexion and less than 60° of involved cervical rotation had Sensitivity values of 0.89, Specificity values from 0.41 to 0.49 respectively, +Likelihood ratios of 1.5 to 1.8 respectively, and –Likelihood ratios from 0.27 to .023 respectively for potential cervical radiculopathy.19 Unfortunately, as previously noted due to time constraints, specific goniometric cervical range of motion measurements were not taken. However, the authors do not feel that the omission of goniometric measurements negatively impacted the initial treatment plan.

Initial interventions focused on improving cervical and thoracic mobility deficits while symptom provocation and improvement with the Ulnar ULTT did not present until visit five. By combining the results of the MRI and EMG/NCS findings and continual clinical re-examination and subject response to treatment (specifically ulnar nerve mobilization techniques) the final working diagnosis was double crush syndrome involving the C8 nerve root and ulnar nerve. In this case, it would seem highly likely that the subject's ulnar nerve was placed at increased risk of injury secondary to potential compression at the C8 nerve roots, which was only clinically apparent with end-range right cervical rotation. This potential low-level compression, which was able to reproduce symptoms of elbow pain, may have increased the vulnerability and compromise of the ulnar nerve distally.

Entrapment of the peripheral nerves of the upper extremity is frequently associated with work related factors in specific occupations, especially those with increased forces, use of hand grips and vibratory tools, and the performance of repetitive manual tasks.47,48 Several authors have associated these and other such ergonomic factors with an increased risk of carpal tunnel syndrome and other repetitive motion disorders specifically in the field of dentistry.20-22 For example, 9.2% of dentists reported receiving a medical diagnosis of a repetitive motion disorder with more than 40% of those resulting in shortened work hours.20,21 Further, ulnar neuropathy is also the most frequent upper extremity peripheral nerve injury to occur to cyclists due to compression at either the cubital tunnel or Guyon's canal, and is often termed “cyclist's palsy.”13,14 For example, proximal dysfunction at the thoracic outlet has been demonstrated in up to 43% of cyclist with diagnosed distal ulnar neuropathy, suggesting that double crush syndrome was present.13

**Discussion of clinical decision-making and interpretation of examination procedures**

Continual clinical re-examination and reassessment during the initial sessions of physical therapy was a key factor in determining both the proximal and distal nerve involvement. First line testing for any complaints of upper extremity neuropathy should be an upper quarter neurologic screen including dermatomal and myotomal testing.23 This testing found dermatomal changes and myotomal changes indicative of potentially both C8 nerve root and ulnar nerve compromise. Although cervical quadrant testing did not elicit symptoms, end-range right cervical rotation was found to reproduce symptoms at the subject's elbow, but not into the hand. Although imaging and EMG/NCS did not indicate a C8 nerve root compression nor radiculopathy it would seem plausible that the end-range right cervical rotation was able to compression the C8 nerve root enough to elicit clinical signs and symptoms. The subject did not have full cervical ROM, so mobility testing was performed to determine which levels of the cervical spine were causing the gross limitation in ROM. Palpation to
upper back and cervical musculature needed to be included to rule in/out trigger point referrals in the soft tissue, and although increased muscle tone and trigger points were established as subject impairments, these did not change the subject's distal UE symptoms.

Key to this subject case is the continual reassessment of the subject's progress. The limited progression at visit five led to the reassessment of neurodynamics. Even with a negative result with Upper Limb Neural Tension at initial evaluation, the Ulnar ULTT was repeated several times at visit five to ensure its exclusion of potential involvement. With repeated testing, the Ulnar ULTT was found to be positive for eliciting the subject's distal symptoms. At this point, the physical therapist was able to create a secondary working diagnosis and begin treatment on both proximal and distal upper quarter structures.

**Analysis of initial interventions & outcomes**

It has been well accepted that a subject's clinical presentation, in collaboration with electrodiagnostic tools such as EMG/NCS, provide reliable results to assist in the diagnosis of upper extremity neuropathies, however, evidence on treatment approaches are currently limited. A systematic review by Wong et al found that 83% of subjects had nearly full resolution of symptoms with conservative treatment (e.g medication, heat, ultrasound, massage, traction, electrical stimulation, neck mobilization, collar use, postural rehabilitation, and progressive resistive exercises). Unfortunately, the decision making, dosage, sequencing, and other details regarding these interventions is not described further. It is suggested that conservative treatment should be attempted first for all subjects without central cord involvement; however, there is limited literature on treatment types. The use of mechanical traction, manual therapy, and therapeutic exercise individually and in combination has been shown to improve functional outcomes in the short term in patients with cervical radiculopathies. However, even though these forms of interventions were initially used in the treatment of the subject of this case report their inclusion demonstrated minimal effect on improving the subject's symptoms. Treatment of isolated peripheral nerve entrapment often includes stretching, soft tissue mobilization, corrective exercises, and neural mobilizations. Related to this case report, incorporation of neural mobilizations of the ulnar nerve demonstrated substantial changes in the subject's symptoms, function, and ultimate outcomes.

Evidence continues to support applying the knowledge of neurodynamics and investigating the role of neural mobilization as a treatment technique. A study of cadavers demonstrates that upper limb neural tensioning techniques increase tensions across the course of the nerve. Similarly, additional neural mobilization techniques, often called nerve glides and nerve slides have been shown to cause changes in neural excursion without significant increases in tension. Based on the treating physical therapist's clinical reasoning and the consideration of the acuity, mechanism of injury, and the response to treatment, applying a neural sliding technique was successful in the treatment of this subject's upper extremity neuropathy and the restoration of normal neurodynamics.

There is minimal evidence demonstrating optimal treatment techniques and intervention dosage for the subject of this case report. Thus, initially the treating physical therapist decided to treat impairments that were directly related to the subject's functional limitations. As a dentist, this subject inherently is required to be able to sustain prolonged periods of cervical flexion. Such sustained postured requires both adequate joint mobility and appropriate endurance of his deep cervical neck flexors muscles and cervical/thoracic extensor muscles. Joint mobilizations to both thoracic and cervical spine were performed to improve mobility and therefore cervical flexion range of motion, and deep neck flexor activation and strengthening interventions were performed to improve maintenance of neutral spine posture with prolonged positions. Scapular strengthening interventions were also aimed to improve subject's scapulothoracic mechanics, endurance, and posture both statically and dynamically. Future research should focus on identifying types of subjects or subgroups who are most likely to benefit from neural mobility interventions as well identifying the dose response to such interventions.

**CONCLUSION**

This case report presents a subject with strong risk factors and clinical signs and symptoms suspect of a
The subject made a full and unrestricted recovery to work and cycling following physical therapy despite recommendations from other health care providers for more invasive interventions. This was supported by subject reported outcomes, clinical examination, and diagnostic testing (EMG/NCS) results. This case highlights the need for continual assessment and re-evaluation of subjects' signs and symptoms especially if current interventions are not eliciting desired responses.

REFERENCES


ABSTRACT

Background and Purpose: The incidence of running related injuries remains high despite numerous efforts to understand the mechanical contributors to the etiology of these injuries. In light of continued running injury, theories of neuromuscular control, or movement patterns, have been suggested as possible contributors to running related injuries. However, the clinical decision making determining when altered neuromuscular control strategies may be affecting a runner’s symptoms has not been described. Therefore, the purpose of this case report is to describe the clinical reasoning within the ICF framework for a runner with hip pain and neuromuscular control dysfunction.

Case Description: A 47-year-old, experienced, female runner presented with posterior hip pain and radiating posterior thigh pain limiting her ability to participate in running and threatened her goal to run in an upcoming marathon. Several features of her examination indicated soft tissue muscular irritation of the posterior hip complex related to impaired balance and control of the lower quarter during functional movement and running activities consistent with a neuromuscular control dysfunction. Her initial Focus on Therapeutic Outcomes (FOTO) score was 69 with predicted change score of +7.

Outcomes: The subject was able to achieve her goals including a return to participation in her weekly running routine and competing in a marathon race. Objective examination features of range of motion, strength, and control of movement were all improved. Her reported function was greatly improved with a final FOTO score 98.

Discussion: The diagnosis and treatment of running related injuries remains a clinical challenge. This case report describes the examination and clinical reasoning in diagnosing neuromuscular control dysfunction and proposes a treatment progression to address this functional limitation. The decision making scheme is also structured to follow the International Classification of Functioning, Disability, and Health.

Level of evidence: 4

Key words: Hip, movement system, piriformis syndrome, running

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or neuromuscular control dysfunction (i.e. Selective Functional Movement Assessment, Functional Movement Screening™, the Lateral Step Down Test, Landing Error Scoring System, etc.). These tests and measures aim to identify gross movement patterns or limitations in movement that may be affecting function with other activities. If neuromuscular control dysfunction is identified with these tests, the clinician can begin to reason that there is a greater likelihood of similar deficits with higher level tasks either causing or contributing to pain and/or injury in the athlete.

Once neuromuscular control dysfunction is identified, it behooves the clinician to begin hypothesizing relevant causes underlying those deficits (i.e. strength, endurance, coordination, proprioception, flexibility, joint mobility, etc.). One proposition regarding neuromuscular control dysfunction is that the demand of a given task exceeds the strength or endurance capacity of the musculoskeletal system preventing adequate control of relevant motions necessary to complete the task.

For example, patellofemoral pain has been linked to strength deficits at the hip as well as neuromuscular control dysfunction of the gluteal musculature. Specifically, onset of muscle activity of the gluteus medius appears to be delayed in female runners with patellofemoral pain. Noehren et al. hypothesized that this delay in muscle activity may contribute to the altered hip adduction and internal rotation observed in runners with patellofemoral pain. If one continues to hypothesize how the musculoskeletal system may attempt to compensate for a delay in gluteus medius activity or a deficit in gluteal strength, it is possible that the individual may utilize increased force production from the piriformis or other hip abductors and external rotators to help control this motion of the hip. This increase in force production from the piriformis may lead to fatigue and accumulation of abnormal stress to this muscle resulting in irritation and/or pain in either the piriformis (as the force production of this muscle may increase) or the gluteus medius/minimus (as these muscles are attempting to control a load greater than they are capable of managing), or both.

Different movement screening methods have been developed to assist clinicians with the identification of potentially disadvantageous movement patterns or neuromuscular control dysfunction (i.e. Selective Functional Movement Assessment, Functional Movement Screening™, the Lateral Step Down Test, Landing Error Scoring System, etc.). These tests and measures aim to identify gross movement patterns or limitations in movement that may be affecting function with other activities. If neuromuscular control dysfunction is identified with these tests, the clinician can begin to reason that there is a greater likelihood of similar deficits with higher level tasks either causing or contributing to pain and/or injury in the athlete.

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muscle forces is sufficient to maintain a given kine-
matic profile, or “preferred movement path”. None-
theless, this shift would alter the kinetic distribution
of forces across tissues in the hip. Thus, identifica-
tion of other components of neuromuscular control
may be helpful to infer neuromuscular control dys-
function in the etiology of hip pain in runners in
addition to running gait analysis.

Clearly, the nature of many neuromusculoskel-
etal conditions can be quite complicated and the
nuances of individual subject presentation can
make the management of subjects (from examina-
tion and evaluation, to intervention planning and
goal setting) very challenging. In light of this, the
use of common language, documentation, and clin-
ical reasoning schemes have been proposed.21 In
2008, the American Physical Therapy Association
endorsed the use of the International Classification
of Functioning, Disability, and Health (ICF) as one
such organizational scheme.24

The ICF is an integrative model which seeks to
consider the human experience of functioning as a
resultant interaction between an individual’s health
condition and his or her personal attributes while
also considering environmental and contextual
influences.25 In addition to this, the model also seeks
to create a systematic and encompassing framework
as a reference to navigate through the process of
subject management.26,27 Therefore, the purpose of
this case report is to describe the clinical reasoning
within the ICF framework for a runner with hip pain
and neuromuscular control dysfunction.

CASE DESCRIPTION

Subject History and Systems Review
The subject was a 47-year-old female experienced
runner (Ht: 155.5 cm; Wt: 51.6 kg; BMI: 21.34)
referred by her primary care provider with a medi-
cal diagnosis of right sided piriformis syndrome.
Symptoms began approximately two months prior
to initiating physical therapy. She described the
onset of symptoms as having occurred after running
a 15 mile trail race. She noted having had to drive
eight hours the day prior to the race. She had some
familiar sensation of tightness in the hip leading
up to this race, but in the subsequent weeks follow-
ing the race, she began to notice buttock pain and
symptoms down the leg which were preventing her
from increasing her running mileage. She denied
any other changes in her training regimen regarding
running frequency, mileage, intensity, or terrain.
She had been consistently using the same model
of footwear and had not used any type of insert or
orthotic.

Treatment had consisted of self-management of
symptoms with stretching, and soft tissue foam roll-
ing of the hips and thighs, but symptoms continued
to increase as she attempted to further her training.

Relevant clinical history included multiple overuse
type injuries including bilateral iliotibial band syn-
drome; right-sided Achilles tendinopathy, plantar
fasciitis, and meniscectomy of the knee; and left-
sided patellar tendinopathy and piriformis syndrome
similar to her current symptoms. Her previous left-
sided hip pain was reported to be less severe than
her current symptoms and spontaneously resolved
with stretching and a brief period of reduced run-
ning mileage. No other health conditions or medi-
cal problems were identified by the subject upon
questioning.

Her primary goal was to be able to resume her train-
ing regimen and progress her running distance in
preparation for a scheduled marathon four months
from the date of her initial presentation.

CLINICAL IMPRESSION #1

From her clinical history of multiple previous over-
use injuries, her primary participation restrictions,
activity limitations and environmental factors were
determined and are described in Figure 1. These
limitations and her reported symptoms led to the
inclusion of multiple diagnoses within the hypoth-
esis list of potential health conditions.

The onset and location of her pain and the history of
multiple soft tissue injuries placed piriformis muscle
irritation as a primary consideration in differential
diagnosis, but additional symptom generators were
considered including gluteal muscles, sacroiliac
joint, the lumbar spine, and adverse neurodynamics.
Given the subject’s history of multiple overuse type
symptoms, the hypothesis that some chronic issues
may be present with her running pattern was gen-
erated. This was thought to increase the likelihood
Figure 1. Integration of examination features within the International Classification of Function (ICF) framework of patient management. Adapted from Atkinson, 2011.

of neuromuscular control dysfunction being present with examination.

EXAMINATION
At her initial visit, pain was located in the right buttock. Symptoms were rated 1/10 at rest and would reach 4/10 after periods of prolonged sitting or after runs exceeding five miles in distance. As symptoms increased some radiation into the posterior thigh was noted by the subject.

Functional limitations included a need to frequently reposition due to discomfort with sitting and reduced tolerance to running, hopping, and lifting. Her intake score on the Focus on Therapeutic Outcomes (FOTO, Inc.) hip inventory was 69 compared to a risk adjusted score of 54 with a predicted change score of +7.

A functional movement assessment was utilized to assess gross movement patterns which revealed deficits in total motion in standing forward flexion, extension and rotation (Table 1). Categorical assessment of these motions has previously been shown to be reliable.20 However, gross visual estimations of quality and quantity of motion were utilized as opposed to categorical groupings to assist with assessment of change of quality of motion. The reliability of the methodology utilized in this case report has not been studied.

Single leg balance with eyes open was appreciated as symmetric as she was able to hold the test position greater than 30 seconds with similar stance quality as assessed by trunk sway, knee and ankle excursion and ability to hold the opposite hip at
and reduced hip extension was observed, bilaterally. However, provocation of symptoms occurred during right stance. Dysfunctional movement was also observed during a squat as evidenced by early heel lift, minimal posterior weight shift, anterior knee position, and reduced knee flexion range of motion.

Further breakdown of impaired movement included assessment of hip range of motion and flexibility using standard goniometric measurements or visual estimation. Overall limitations in range of motion were present, bilaterally. End range tightness was

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<th>Table 1. Examination measures</th>
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<td>FOTO</td>
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<td>Multi-segmental Flexion</td>
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<td>Multi-segmental Rotation</td>
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<td>Single Leg Balance (EC)</td>
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<td>Functional Squat</td>
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<td>Hip Passive Range of Motion</td>
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<td>Flexion</td>
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<td>Internal Rotation (supine)</td>
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<td>Internal Rotation (prone)</td>
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<td>External Rotation (prone)</td>
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<td>Flexibility Tests</td>
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<td>Hamstring 90/90</td>
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<td>Piriformis</td>
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<td>Hip Strength (MMT)</td>
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FOTO=Focus on Therapeutic Outcomes; NPRS=Numeric Pain Rating Scale; EC=eyes closed; MMT=manual muscle test; ROM=range of motion; ~ = indicates that motion was visually estimated by the examiner.
appreciated during hip flexion and piriformis flexibility testing and provocation of symptoms occurred with piriformis flexibility testing (Table 1). Manual muscle testing revealed symmetric mid-range isometric strength with decreased strength present bilaterally for hip abduction, internal rotation, and external rotation (Table 1). Endurance testing included repetitive concentric hip abduction with the subject reporting increased fatigue on the right leg compared to the left over the same number of repetitions.

Palpation only assessed whether the subject reported tenderness and whether that tenderness was similar to her reported symptoms. No attempt was made to identify trigger points or myofascial restriction as the reliability of manual assessment has been questioned. Palpation revealed primary symptoms located in the center of the buttock between the inferior-lateral sacral angle and greater trochanter over the course of the piriformis muscle belly. She had no tenderness to palpation or mobility assessment of the lumbo-sacral region or along the iliac crest. Sacral thrust test was also negative.

**CLINICAL IMPRESSION #2**

After examination, a list of specific impairments of body structure/function was created including limited hip and lumbar range of motion, decreased single limb dynamic balance and kinesthetic awareness with coordination/control during lower extremity functional squat and dynamic leg motions (Table 1). Furthermore, evaluation of these specific impairments made it possible to hypothesize underlying contributors and potential causes of these impairments, similar to diagnosing an underlying health condition.

As lumbar motion did not provoke her symptoms, no tenderness was present with palpation or segmental mobility assessment of the lumbar spine, and piriformis flexibility test reproduced her primary symptoms, it was reasoned that her symptoms were being generated from muscular dysfunction of the posterior hip as opposed to possible lumbar or sacroiliac dysfunction. Additionally, she demonstrated deficits with hip abduction endurance and corrective balance strategies at the hip. Symptoms were provoked during dynamic balance and underlying limitations in multi-segmental motion of the hip and lumbar spine. And, she demonstrated a dysfunctional squat. Thus, it was hypothesized that her symptoms were likely a result of neuromuscular control dysfunction about the hip region. This was further supported by overall loss of rotational motion of the hip and specific flexibility deficits of the rectus femoris (Ely's test) and tensor fascia latae and iliotibial band (Ober's test) suggesting length changes of the hip musculature. Also, given her history of multiple overuse type injuries, it was reasoned that these deficits may have been long standing and present prior to her current symptoms.

Running gait was not assessed, therefore, it is unknown whether altered running mechanics were present. However, the above findings supported the initial hypothesis of neuromuscular control dysfunction, and treatment was initiated to address those impairments identified during her examination.

**INTERVENTION**

The subject's primary activity limitation was with the task of running, which threatened her primary goal of participation with an upcoming marathon. The treatment plan was organized to allow her to continue with the activity of running and permit gradual progression towards her ultimate participation goal.

Exercise prescription was aimed at addressing her primary impairments of body structure/function namely reduced hip muscle strength and endurance, difficulty with balance, and neuromuscular control.

Her initial home program consisted of seated hip external rotation against resistance to facilitate hip external rotation strength in a position that would eliminate the influence of the piriformis muscle. Side-lying hip abduction to address the reported increased fatigue during hip abduction strength testing, and single leg balance with leg swings to address pelvic control during stance. As she reported aggravation of her symptoms with running distances greater than five miles, she was instructed to limit her running to no greater than five miles at a time. She was also instructed to monitor her symptoms, and if she were to have symptoms when running at what distance she began to notice them. Furthermore, she...
Visit #2
At her next appointment, two weeks later, she reported having had to cease running as her symptoms were aggravated by this activity. She noted that over the prior 10 days of no running and consistency with her home exercise program that she had less discomfort in the buttock and could tolerate sitting for longer times with fewer symptoms into her leg. Given the increase in her symptoms with continued efforts at running, she was instructed to refrain from running for the following week and to replace her typical running workouts with an updated home program including the above mentioned exercises with the addition of single leg balance with rotation, half kneeling balance, and walking lunges (Figure 2). Balance exercises were included to begin working on proprioception and neuromuscular control through the hip. Walking lunges were included to mimic running technique. Specific instructions including slow and controlled motion during eccentric lowering of the front leg were given in an attempt to facilitate carry over from static exercises to more dynamic exercises.

Visit #3
A week later she noted having independently attempted a plyometric workout which resulted in an acute increase in her symptoms resulting in a return of posterior leg discomfort and increased buttocK pain. Physical examination findings showed loss of hip flexion (right = 115 degrees; left = 125 degrees) and internal rotation (right = 25 degrees) motion. Palpable tenderness was also increased in the gluteal muscles and the piriformis with tenderness most pronounced into the gluteus medius and minimus.

Given the increase in her symptoms, measurable loss of range of motion, and increased muscular tenderness with palpation, dry needling was incorporated into her treatment regimen. It was reasoned that the

Figure 2. A proposed progression of increasing dynamic components of exercise to challenge components of neuromuscular control. Single leg balance is completed in running stance position with stance knee flexed approximately 30 degrees and opposite hip flexed to near 90 degrees. Single leg balance with leg swings is completed with the stance knee flexed to near 30 degrees and the opposite leg swings from slight extension to 90 degrees of hip flexion with focus on pelvic control and knee stability. Walking lunges are completed with emphasis on controlling both the eccentric and concentric components of the exercises focusing on knee position remaining over the stance foot. Reverse lunges are completed by reaching backwards and completing the eccentric lowering of the body on one leg only.
increase in muscular tenderness may be the result of acute change in activity resulting in an applied load which exceeded the muscular capacity to complete the plyometric tasks she attempted. This novel load may have contributed to the progression of latent trigger points to active trigger points causing an increase in pain in the hip and referral to the posterior thigh.

Dry needling was performed addressing the gluteus medius and minimus as this was the area of greatest tenderness and the gluteus minimus has a stronger referral pattern to the posterior thigh than does the piriformis. Two-three needles (Myotech, Shanghai Kangnian Medical Device Company, Shanghai, China) were used for each muscle. Needles were manipulated in an up and down motion in attempts to elicit a twitch response. Only these muscles were treated to help differentiate between the gluteus medius/minimus and the piriformis as potential sources of her current pain. This resulted in a within session improvement of 10 and 15 degrees for passive hip flexion and internal rotation, respectively. She was instructed to continue with her home program and to continue to refrain from running and plyometrics.

Visit #4
At her next visit (one week later), she noted much improvement in her resting symptoms and tolerance to prolonged symptoms, and absence of posterior leg discomfort. However, some continued discomfort into the buttock was present. Hip internal rotation was pain free, and it was end range external rotation which reproduced her buttock symptoms at 55 degrees. Thus, an additional treatment of dry needling was performed.

Dry needling was performed again to the gluteus medius/minimus, but also included the piriformis. By adding treatment of the piriformis, while keeping previous treatment of the gluteus medius/minimus the same as her previous visit, clearer insight regarding her remaining symptoms was desired to discern between involvement of the gluteals and the piriformis. She demonstrated an increase of 10 degrees in passive external rotation motion following treatment.

As her symptoms appeared to be improving from a combination of rest and treatment, progression toward returning to a running program was made. Her home program was advanced to include further dynamic control of the stance leg in the form of a reverse lunge to increase the vigor of her previous lunge exercise by moving from double leg support to single leg support (Figure 2), and to mimic the single leg eccentric control required during running.

Visit #5
The subject had refrained from running for one month and her primary goal of participating in a marathon was being jeopardized. Upon arrival, she noted complete absence of any posterior leg symptoms and buttock pain and no provocation of symptoms with any daily activities or her home exercise program. She demonstrated symmetric single leg balance, no provocation of symptoms with single leg balance in conjunction with contralateral leg swings, and improved control of motion with reverse lunges. Given these findings, no provocation of symptoms with previously symptomatic exercises, and her goal of participating in a marathon in three months' time, it was determined that an accelerated return to run program would be incorporated and consideration was given to the use of a body weight support (BWS) running system (Figure 3) to compliment a graded return to running program to allow more rapid increase in running volume.

A two-dimensional running analysis was completed to assess her tolerance to overground running and for qualitative gait assessment. Lower extremity control appeared symmetric with no concerning dynamic valgus, hip drop, or excessive pronation. Tibial angle demonstrated a mild posterior incline in conjunction with a clear rearfoot strike pattern. Cadence was measured as 170 steps per minute (spm).

Cadence manipulation was completed using an approximate 5% increase to 178 spm to attempt to reduce the load being placed upon the hip musculature. She then completed two sets of a five minute walk/jog routine without provocation of symptoms and thus was instructed to begin a return to running program at home. She was to utilize a metronome to maintain a cadence of 178 spm during these runs.

In order to allow more rapid increases in her running volume and to attempt to create carry-over from her neuromuscular control exercises to her running pattern, it was agreed to use the next several clinic appointments to progress her running volume via the use of a BWS system.
to have the support bars placed 12 inches above the greater trochanter which resulted in 26.2 lbs of her body weight supported by the system. She progressed her running time by 10 minutes each week. This progression continued until two weeks prior to the scheduled marathon. Her home running program was progressed in a similar fashion by completing two overground running days each week with incremental increases in total running time of five minutes with each subsequent run (Table 2). Time increases were selected such that a consistent increase would occur throughout the subject’s running progression while staying below any increase in running volume exceeding 30%.33

OUTCOMES

The primary outcome utilized for this study was her ability to participate in and complete a scheduled marathon. At her final follow-up visit, three weeks after this race, she reported having completed the full marathon with a time of 4:00:39 where she was able to run the entire distance other than walking through a few aid stations.

She noted overall status as 80% at three weeks following the marathon after some increased soreness and feelings of tightness following the race. She felt that her symptoms were improving with her home program and were not limiting her running. Her FOTO score improved by 29 points compared to an age predicted physical change score of +7.

Impairment measures of hip range of motion, strength, and functional movements were all improved at her final visit (Table 1). Goniometric measures of hip range of motion are considered to be acceptable measures to track clinical change and the differences measured

Visits #6-12

These seven visits were scheduled once weekly and consisted of gradual progression of her overall running distance using the BWS system. Unloading was selected according to manufacturer recommendations

<table>
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<td>7</td>
<td>80 minutes</td>
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<td>8</td>
<td>60 minutes</td>
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<td>Race</td>
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BWS=Body weight support

Figure 3. Photograph of the body weight support system utilized in this case report. The harness is fastened around the subject’s legs with elastic cords attached to the support frame which is mounted around the treadmill.
exceeded the reported standard error of measure.\textsuperscript{34} Manual muscle testing has been reported as reliable and is a common method employed by physical therapists to track gross improvement in strength.\textsuperscript{35} Changes in strength were detected in this case and accompanied with a noticeable qualitative improvement for abduction and rotation in prone. Although a categorization scheme was not utilized in this study to assess change in functional movements, the qualitative and quantitative measures were improved. This in combination with her reduction in symptoms suggests a change in these motions occurred although this cannot be stated as the psychometric properties of these measurements have not been determined.

Lastly, a reassessment of her running gait completed three weeks after her marathon revealed a cadence of 176 spm, while the kinematic profile of the lower extremity was similar to her previous analysis.

\textbf{DISCUSSION}

The etiology of RRIs is multifactorial and requires sports physical therapists to take a holistic and comprehensive approach to subject management to facilitate examination and evaluation as well as treatment planning. Further, consideration should be given to any underlying health conditions as well as primary impairments to make hypotheses regarding the source of a subject's symptoms in order to curtail treatment selection and to allow complete amelioration of symptoms. Without inference into the underlying cause of a subject's pain, recurrent issues may develop. Thus, the primary aim of this case report was to highlight the clinical reasoning process in establishing a hypothesis of muscular irritation due to neuromuscular control dysfunction in an experienced runner. This reasoning process is also integrated within the suggested ICF model of subject management.

The approach to this case began with utilizing the ICF model and considering the subject's primary activity limitations and participation restrictions. By determining her primary limitations as occurring with the task of running resulting in reduced participation with social group runs and possibly prohibiting her from participating with a scheduled marathon, mutual goals were established and treatment was curtailed towards improving her ability to complete these activities.

From determination of her primary limitations, the subjective history focused on discerning salient external factors that may have impacted her plan of care. These included internal and external modifiers (Figure 1). It was upon consideration of the multiple reports of previous overuse type injuries in an experienced runner who reported no obvious training errors that the hypothesis of neuromuscular control dysfunction as an underlying impairment affecting her health condition of muscular pain and irritation was generated.

This process of hypothesis generation has been described as forward reasoning.\textsuperscript{36} With subsequent questioning, additional components of the subject's history were also consistent with muscular irritation including the insidious onset, the location of symptoms, and the posterior leg pain with absent neurological symptoms. To test the hypothesis of these muscular symptoms being the result of neuromuscular control dysfunction, examination and evaluation of impairments of body structure and function were completed with findings supporting this hypothesis.

Given the subjects continued participation with running and high level of reported function, examination began with assessment of functional motion. She demonstrated gross deficits in multi-segmental motions in both the sagittal and transverse planes (limited standing forward flexion and extension and composite rotation < 90 degrees) along with aberrant motion during functional squats and deficits with single leg balance. These deficits supported the primary hypothesis of neuromuscular control dysfunction. Further, the absence of pain or reproduction of symptoms with multi-segmental flexion and extension were findings which would not be expected if her symptoms were lumbar in nature.

She demonstrated slight deficits in range of motion from normative values,\textsuperscript{37} but these deficits were present bilaterally. Further, she had gross flexibility deficits in muscles which either controlled multiplanar motion or were biarticular in their attachment (i.e. the piriformis, hamstrings, rectus femoris, and IT band). The deficits in range of motion and flexibility of multiplanar and biarticular muscles may have been caused by these larger muscles compensating for stability, or control, deficits from more intrinsic musculature at the hip and/or knee.\textsuperscript{38} With
these deficits being bilateral, the underlying cause behind these motion deficits was likely not due to an increase in muscular tone in the presence of pain on the involved limb. Thus, it was reasoned that these bilateral deficits were due to a developed tone resultant from the neuromuscular control dysfunction detected with multi-segmental and functional motions which supported the primary hypothesis.

Lastly, it was important to rule out the lumbar spine and SI joint involvement. As lumbar segmental mobility and sacral thrust tests were negative, multi-segmental motion did not produce any pain in the back or near the SI joint, and other tests were supportive of neuromuscular control dysfunction, it was reasoned that it was possible to infer neuromuscular control dysfunction as the best explanation of her symptoms. And, treatment addressing neuromuscular deficits demonstrated a return of lumbar and hip ROM without specific interventions addressing the lumbar spine.

Initial treatment focused on addressing noted impairments of body structure and function, through hip strengthening and balance exercises. Due to underlying neuromuscular control dysfunction, dynamic components to balance exercises were incorporated (i.e. leg swings during single leg balance). As the primary hypothesis was that her symptoms were a result of neuromuscular control her treatment was progressed by increasing the challenge of balance and control instead of adding resistance to the selected exercises (Figure 3).

For example, single leg balance with leg swings was progressed to a walking lunge with a pause in single leg stance position. This was then progressed to a reverse lunge requiring her to maintain single leg stance through a larger excursion of hip and knee range of motion while maintaining balance. This progression was selected also to attempt to mimic aspects of her primary activity limitation (i.e. running).

After several weeks of this training, and allowing the irritability of her symptoms to reduce by restricting her running, it was hoped that a foundation of neuromuscular control of the lower extremity could be built such that when she did resume running, she would be able to do so without aggravating her symptoms. This seems to have been the case as she was able to progress through an accelerated running program without provocation of pain.

As symptoms resolved it was deemed appropriate to examine her running gait. This revealed an interesting aspect of her clinical presentation as numerous components of her clinical examination demonstrated difficulty with neuromuscular control, but her running gait analysis showed no adverse motions at the hip or knee. Here the authors would like to suggest that neuromuscular control dysfunction may be present even in the absence of visible movement faults.

A recently proposed running injury paradigm (“the preferred movement path”)[11] suggests that muscle activity is used to ensure that skeletal motion remains on a certain path while the degree of that movement can vary between individuals and depending on the conditions of the task. As muscle activity can vary to maintain this path, the control strategy being utilized by an individual may still be “altered”, but the observed kinematics may look normal. It is hypothesized that this was occurring in the above case.

As the subject demonstrated multiple control deficits with lower level tasks including single leg balance, squats, and multi-segmental motion, it was reasoned that it was likely that similar deficits with control would be present during running. However, as her gait analysis showed no overt qualitative faults, it was hypothesized that she had developed a control strategy utilizing alternative muscle combinations.

Specifically, given that she had evidence of reduced gluteal endurance she may have developed a strategy where she utilized increased piriformis muscle force to control hip adduction[22] leading to overuse and pain in that muscle. Or, the increased utilization of the piriformis muscle may have allowed her to reduce the load to the gluteus medius and minimus and could partially explain the reduced endurance of these muscles. This reduced endurance may have predisposed her to irritation of these muscles as she attempted to increase her mileage. Whether the pain generating muscle was the piriformis, the gluteus medius, gluteus minimus, or some combination of all three is not known with certainty, but an altered muscular recruitment strategy as outlined above could explain an injury to any of them.
To treat this, a two-fold approach was taken to reduce the load being placed on the hip musculature. First, her step rate was increased by approximately 5%. This was done to address potential gait faults of posterior tibial inclination, foot inclination, and heel-to-COM distance. By reducing these aspects of her gait, vertical ground reaction forces may also be reduced and thus propagate less loading to the involved hip muscles. Further, step rate increases have also been shown to directly reduce the muscle force requirements of the gluteus medius, gluteus minimus, and piriformis. She was instructed to incorporate this increase in step rate for all of her runs outside of the clinic.

The second approach taken to reduce the load to the hip muscles was to utilize BWS treadmill running. The use of BWS during running has been shown to reduce vertical ground reaction forces and rates of loading as well as intra-muscular pressures of the lower leg. Thus, this was utilized to further reduce the load to the hip musculature. Utilization of this device was done for her weekly long runs to accelerate the building of her running volume in preparation for her upcoming marathon race. The amount of unloading was held constant and the time of running was progressed with each week (Table 2). This was done to allow physiological adaptation of the muscles to the accumulation of reduced loads over the duration of her runs as opposed to gradually transitioning her back to tolerate running under full body weight conditions.

The subject was able to progress through the combined running program of step-rate modification and BWS treadmill running without provocation of symptoms and was able to increase her running mileage such that she was able to successfully complete her primary goal of participating in a marathon race.

LIMITATIONS
It is important to note that the primary hypothesis of muscular irritation of the piriformis muscle was not diagnostically confirmed, but was rather a conclusion based on interpretation of available examination data on her movement quality and its potential impact on the movement system during the task of running. Only one sacroiliac joint test was completed, which may have left any contributing dysfunction there undetected. And, core muscle function was not assessed and thus we are not able to determine what contribution these muscles may have had on the subject’s presentation.

Inherent to case report methodology and the fact that no control was used for comparison, it is not possible to state if any of these interventions were the cause of her improvements. Further, it cannot be stated with certainty which component of the intervention plan led to her improved status. This case report only serves to present and highlight the reasoning process employed to arrive at the treatment strategy utilized.

Finally, it cannot be stated if the intervention actually resulted in a changed muscular strategy during running or assessment of functional motion. However, improved quality of motion was observed upon re-evaluation. This implies that improved movement control was present. Further study using musculoskeletal modeling techniques investigating estimates of muscle force production and EMG analysis would be required to elucidate what types of muscular activation and force strategies occurred resulting in the changed quality of motion.

CONCLUSION
The diagnosis and treatment of RRI s remains a clinical challenge. This case report highlights how features of the examination may assist in diagnosing neuromuscular control dysfunction as a relevant feature of the movement system and how that can lead to symptom provocation during specific movement tasks. Recognition of neuromuscular control dysfunction may then afford focused treatment progression to address functional limitations and may lead to successful return to activity.

REFERENCES
3. Davis IS, Bowser BJ, Mullineaux DR. Greater vertical impact loading in female runners with medically


ABSTRACT

Introduction: Management of mid-portion Achilles tendinopathy is a challenge for both clinicians and researchers. Alteration in tendon structure, muscle performance and pain processing mechanisms have been suggested as mechanisms driving improvement in pain and function. However, few trials have used consistent outcome measures to track changes in pain and function.

Objectives: 1) To identify all outcomes measures used in trials utilizing exercise-based interventions for mid-portion Achilles tendinopathy (AT) that assess self-reported pain and function and to report on the reliability and validity of the identified measures, and 2) Propose measures to optimally assess self-reported pain and function in patients with AT.

Design: Literature Review

Data Sources: Three major electronic databases were searched from inception until May 2016 for studies using isometric, eccentric or isotonic loading protocols for mid-portion AT.

Eligibility Criteria: Randomized and non-randomized trials of isometric, eccentric or isotonic loading in people with mid-portion AT.

Results: Forty-six studies were included and all outcome measures assessing self-reported pain and function were extracted. While a variety of outcome measures have been used, few have provided reliability data. There is evidence to suggest that the Victorian Institute of Sports Assessment- Achilles (VISA-A) is the only valid and reliable measure of self-reported pain and function for people with mid-portion AT. No other outcome measures have been validated in mid-portion AT.

Conclusion: The VISA-A remains the gold standard for assessing pain and function in mid-portion AT. However, while the validity or reliability of the Numerical Rating Scale (NRS) of pain during a functional task has not been established it may be a better measure of immediate treatment effect.

Level of evidence: 5

Key words: Achilles; outcome measures; reliability; tendinopathy; validity
The objectives of this review were: 1) To identify all outcomes measures that have been used in trials that involved exercise based interventions for mid-portion AT assessing self-reported pain and function, and to report on the reliability and validity of the identified measures; and 2) Recommend those measures that optimally assess self-reported pain and function in patients with AT.

METHODS

Criteria for considering studies for this review

Types of studies
Both non-randomized cohort studies and randomised controlled trials were included if a loading protocol was used to treat mid-portion AT. Case reports, clinical observations and systematic reviews were excluded.

Types of participants
Physically active and sedentary participants aged 18 years and over identified as having mid-portion AT for greater than three months were included. Studies including participants with insertional AT or other causes of pain (differential diagnoses) anywhere in the Achilles region were excluded from the review.

Types of interventions
Intervention studies using either isometric, eccentric, concentric or isotonic (eccentric and concentric) loading protocols were included. Studies that employed an isometric, eccentric, concentric or isotonic loading program in conjunction with a placebo therapy (for example sham laser treatment) were included.

Types of outcomes measures
Only studies that used a self-reported measure of pain and function in mid-portion AT were included.

Search methods for identification of studies

Electronic Searches
Searches using free text terms (Table 1) were used to identify published articles on the following electronic databases; PUBMED, CINAHL (Ovid) and CINAHL (EBSCO). Only peer reviewed, human, clinical trials and cohort studies were included.
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provided a reference to psychometric properties, the referenced study was used to extract the data.

RESULTS

Selection of Studies
A total of 46 studies were included and are presented in a Prisma Flow Chart (Figure 1).

Data Extraction
All studies using a loading intervention for mid-portion AT used a measure of self-reported pain and function. The characteristics of the included studies are presented in Appendix A.

Data Synthesis
The outcome measures used to assess pain and function in the interventional clinical trials are presented in Table 2. Most outcome measures in this domain did not report their reliability and have not been validated in mid-portion AT.

Victorian Institute of Sport- Achilles
The Victorian Institute of Sports Assessment-Achilles (VISA-A) has been used in 28 clinical trials and was the most frequently used outcome measure to assess pain and function. The VISA-A has excellent reliability (test-retest $r = 0.93-0.98)^{55}$ and is the only

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**Table 1. Systematic Review Search Strategy**

<table>
<thead>
<tr>
<th>Number</th>
<th>Combiners</th>
<th>Terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Problem of Interest</td>
<td>Achilles tend*</td>
</tr>
<tr>
<td>2</td>
<td>Intervention</td>
<td>exercise OR eccentric OR isotonic OR resistance OR strength*</td>
</tr>
<tr>
<td>3</td>
<td>Limitations</td>
<td>#1 AND #2 Peer reviewed, human, clinical trials written in English</td>
</tr>
</tbody>
</table>

**Searching other Resources**
Reference lists from reviews and retrieved articles were checked and citation searches on key articles performed. The list of included studies were evaluated by content experts to help identify any additional relevant studies.

Data collection and analysis

**Selection of Studies**
One review author (MM) independently searched and assessed the titles and abstracts of potential studies identified by the search strategy for their eligibility. Studies were exported to reference management software EndNote X8.0.2 (Clarivate Analytics, 2017) and duplicates were removed. If the eligibility of a study was unclear from the title and abstract the full paper was assessed. Studies that did not match the inclusion criteria for this review were excluded. Studies were not anonymised prior to assessment.

A PRISMA study flow diagram$^{12}$ was used to document the screening process as recommended in Part 2, Section 11.2.1 of the Cochrane Handbook for Systematic Reviews of Interventions.$^{13}$

**Data abstraction and management**
One review author (MM) independently extracted data from all included studies using a standardised and piloted data extraction form on Microsoft Excel (Microsoft, 2016). The following information was recorded; primary author, year of publication, study design, study population (diagnosis), sample size, loading intervention (e.g. heavy eccentric calf training), outcome measures used, number of follow up points and time (weeks) at each follow up point.

**Data synthesis**
Reliability, validity, minimally clinically important difference (MCID) and the minimal detectable change (MDC) were reported if provided by the study using the outcome measure. If the study

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**Figure 1. Prisma Flow Chart.**
Table 2. Outcome measures assessing self-reported pain and function

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Number of Times used in Clinical Trials</th>
<th>Follow up Times (weeks)</th>
<th>Validity</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Analogue Scale of Pain at Rest</td>
<td>0, 2, 3, 4, 6, 8, 12, 26</td>
<td></td>
<td>Assessed against the Numerical Rating Scale in Rheumatoid Disease: r= 0.62-0.9158</td>
<td>Test Retest Reliability in Mid-portion Achilles Tendinopathy: r= 0.4565</td>
</tr>
<tr>
<td>Visual Analogue Scale of Pain with various functional tasks</td>
<td>2, 4, 6, 8, 12, 26, 52</td>
<td></td>
<td>Not Reported</td>
<td>Test Retest Reliability in Mid-portion Achilles Tendinopathy with Jumping: r= 0.6945</td>
</tr>
<tr>
<td>100mm VAS of Pain with 1kg Squeeze of the Achilles Tendon</td>
<td>2, 6, 12, 26</td>
<td></td>
<td>Not Reported</td>
<td>Test Retest Reliability in Mid-portion Achilles Tendinopathy with Heel Raise: r= 0.6145</td>
</tr>
<tr>
<td>4 Point Scale of Pain with 1kg Squeeze of the Achilles Tendon</td>
<td>1, 3, 6, 12, 39</td>
<td></td>
<td>Not Reported</td>
<td>Not Reported</td>
</tr>
<tr>
<td>Numerical Rating Scale of Pain at Rest</td>
<td>2, 4, 52</td>
<td>4, 12, 52</td>
<td>Assessed against the Visual Analogue Scale in Rheumatoid Disease: r= 0.61-0.9158</td>
<td>Test Retest Reliability in Rheumatoid Arthritis: r= 0.95-0.9667</td>
</tr>
<tr>
<td>Numerical Rating Scale of Pain over time</td>
<td>5, 4, 2, 52</td>
<td>4, 12, 16, 26, 52</td>
<td>Not Reported</td>
<td>Not Reported</td>
</tr>
<tr>
<td>5 Point Likert Scale of Difficulty in Sport</td>
<td>15</td>
<td>6, 12, 26, 52</td>
<td>Not Reported</td>
<td>Not Reported</td>
</tr>
<tr>
<td>Victorian Institute of Sport Assessment - Achilles</td>
<td>28, 17, 16, 30, 31, 35, 37, 39, 41, 42, 44, 46, 48, 50-54</td>
<td>2, 3, 4, 6, 8, 12, 26, 24, 26, 36, 52, 2, 2, 2 years</td>
<td>Assessed against the Percy and Conochie’s grade of severity in Achilles Tendinopathy: p&lt;0.0515</td>
<td>Test Retest Reliability in Achilles Tendinopathy: r= 0.93-0.9865 Inter-rater Reliability in Achilles Tendinopathy: r= 0.9045</td>
</tr>
<tr>
<td>Modified Curwin and Stanish Six Level Pain Scale</td>
<td>25</td>
<td>12, 60, 220</td>
<td>Not Reported</td>
<td>Not Reported</td>
</tr>
<tr>
<td>Functional Index of the Leg and Lower Limb (FILLA)</td>
<td>15</td>
<td>2, 4, 6, 12</td>
<td>Not Reported</td>
<td>Not Reported</td>
</tr>
<tr>
<td>American Orthopedic Foot and Ankle Score (AOFAS) Hindfoot Scale</td>
<td>10</td>
<td>6, 12</td>
<td>Assessed against the Foot Function Index in Rheumatoid Arthritis Hallux Pain: p&lt;0.0559</td>
<td>Test Retest Reliability in Rheumatoid Arthritis Hallux Pain: ICC= 0.9551 Intra-Rater Reliability in Rheumatoid Arthritis: ICC= 0.9551</td>
</tr>
<tr>
<td>Short Form-36 (SF-36)</td>
<td>20</td>
<td>4, 6, 12, 26, 52</td>
<td>Assessed against the Visual Analogue Scale of Pain in Rheumatoid Arthritis: r= -0.4851</td>
<td>Test Retest Reliability in General Practice: α= 0.7864</td>
</tr>
<tr>
<td>EuroQoL</td>
<td>20</td>
<td>2, 4, 6, 12, 26</td>
<td>Assessed against the Western Ontario and McMaster Universities Osteoarthritis Index in Knee Osteoarthritis: Spearman’s r=0.20-0.6061</td>
<td>Test Retest Reliability in Kneee Osteoarthritis: 0.70-0.7361</td>
</tr>
<tr>
<td>Foot and Ankle Outcome Score (FAOS)</td>
<td>30</td>
<td>3, 6, 12, 26</td>
<td>Assessed against the Karlsson Score in Foot and Ankle Osteoarthritis: r=0.58-0.6758</td>
<td>Test Retest Reliability in Foot and Ankle Osteoarthritis: ICC= 0.70-0.9245</td>
</tr>
<tr>
<td>Numerical Scale of Physical Activity</td>
<td>15</td>
<td>6, 12, 26, 52</td>
<td>Not Reported</td>
<td>Test Retest Reliability: “satisfactory”63</td>
</tr>
<tr>
<td>Numerical Scales of Improvement</td>
<td>8, 10, 12, 24, 36, 42, 47, 54</td>
<td>4, 12, 16, 26, 52</td>
<td>Not Reported</td>
<td>Not Reported</td>
</tr>
<tr>
<td>Treatment Satisfaction</td>
<td>10</td>
<td>3, 6, 12, 52, 112, 200</td>
<td>Not Reported</td>
<td>Not Reported</td>
</tr>
<tr>
<td>Patient Global Impression of Change (PGIC)</td>
<td>15</td>
<td>12, 26, 52</td>
<td>Assessed against the Self-Assessment of Treatment Scale in Postherpic neuralgia: r=0.68-0.9067</td>
<td>Not Reported</td>
</tr>
</tbody>
</table>

The MCID of an outcome measure is important both for study design (e.g. power calculations), as well as measuring whether or not an intervention reflects a meaningful improvement for the patient.67 The majority of outcome measures reported in the literature to assess pain and function have not yet had outcome measure used in clinical trials that has been validated for AT; it was validated against two tendon pain rating scales, the Percy and Conochie's grade of severity (Spearman's r = -0.58, p = < 0.01)58 and that of Curwin and Stanish (Spearman's r = -0.57, p = < 0.001).58 No MDC has been reported.
the MCID calculated for mid-portion AT. The VISA-A has had the MCID reported for insertional AT with an improvement of 6.5 points reflecting a meaningful improvement for the patient. The MCID of the VISA-A in mid-portion AT has only once been reported in one pilot study, with an MCID of 16 points. However, this study did not provide any information on how the MCID was calculated and it is unlikely using the study design they would have been able to complete calculations required for determining a MCID. However, most clinical trials reviewed here used other scores, with 10 points being the most common MCID reported (Table 3).

In addition to the MCID another psychometric property commonly used is the minimal detectable change. However, none of the papers included in this review which used the VISA-A made any reference to this.

**Visual Analogue Scale and Numerical Rating Scale**

Variations of the Visual Analogue Scale (VAS) (Table Two) and Numerical Rating Scale (NRS) using average pain, worst pain, pain at rest or during functional tasks have been used in sixteen and five clinical trials, respectively. The VAS has been shown to have poor test-reliability at rest in AT (r = 0.45) however this is marginally better when used to assess pain during functional tasks (r = 0.61-0.69). Whilst the VAS has been shown to be valid when tested against a variety of pain rating scales in other conditions (e.g. rheumatoid disease, chronic low back pain, osteoarthritis) it has yet to be validated in AT.

A variety of other self-reported pain and improvement scales have been used in clinical trials however none of these scales have been validated in AT (Table 2).

None of the papers included in this review which used the NRS or VAS made any reference to either the MCID or MDC for these measures in mid-portion AT pain.

**DISCUSSION**

Pain and function have been measured with VISA-A and pain scales including NRS and VAS. However, the timing and instructions of implementing the VAS and NRS differs vastly between trials; for example worst pain today, current resting pain or pain during loading task such as hopping. It is unclear in both a research and clinical setting when these pain and function outcome measures should be used.

The results of this review indicate that the VISA-A is the only validated and reliable measure of pain and function for mid-portion AT. It is therefore recommended as currently being the best primary outcome measure to assess these clinical domains. However, problems do remain when considering utilisation of the VISA-A in clinical practice; firstly, completion of the VISA-A may not be practical for assessing immediate response to treatment. Furthermore, the process used to develop and validate the VISA-A does not conform to current recommendations in developing a self-reported outcome measure and is missing components suggested to be vital in developing a self-reported outcome measure. Given that the VAS and NRS of pain are easily applied and have been validated for musculoskeletal pain in other conditions, they may be more appropriate for assessing immediate treatment effect; however, further research is of course required to establish reliability and validity. Specifically, given that the NRS of pain has been shown to be more reliable, valid and responsive than the VAS of pain in other musculoskeletal pain conditions it may be the preferred choice. Immediate treatment effects have been measured in patellar tendinopathy by comparing the NRS of pain during a provocative functional test (single leg decline squat) before and

<table>
<thead>
<tr>
<th>MCID</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>63, 64, 47</td>
</tr>
<tr>
<td>12</td>
<td>47, 48, 49</td>
</tr>
<tr>
<td>15</td>
<td>50, 51, 52</td>
</tr>
<tr>
<td>16</td>
<td>50, 51, 53</td>
</tr>
<tr>
<td>17</td>
<td>54</td>
</tr>
<tr>
<td>20</td>
<td>55</td>
</tr>
</tbody>
</table>

Table 3. Frequency of the MCID reported for the VISA-A in mid-portion Achilles Tendinopathy in clinical trials using loading protocols.
immediately after a loading program. By mirroring this investigational methodology in AT, further information on the immediate effect of loading on tendon pain can be gathered. However, caution must be taken given that the validity and reliability of the NRS of pain in AT remains unknown.

Improvements have been observed in VISA-A scores in as early as two weeks following commencement of a loading protocol. For both clinicians and researchers, completing a VISA-A at multiple time points during the intervention may help determine the rate of change, and provide insight into the mechanisms relating to improvements based on the temporal response.

While the MCID of the VISA-A has been reported in insertional AT it has not been formally reported in mid-portion AT. No clear consensus exists with the only study which has reported an MCID not providing any information on how the MCID was calculated. Without clear information on how the MCID was calculated we cannot be confident in the results. Currently the authors would suggest that two different methods can be utilized for choosing the MCID for sample size calculations when using the VISA-A as the primary outcome measure in a clinical trial; 1) using the MCID of insertional AT (6.5 points), or 2) using the most commonly reported MCID in clinical trials (10 points). Either of these methods of selecting a MCID for power calculations to estimate sample sizes are appropriate, however they are potential sources of error given the true MCID for mid-portion AT has not been calculated.

The quality of the studies using an exercise intervention for mid-portion AT was very low. A mix of randomized and non-randomized studies existed, each containing small sample sizes. Only four out of 46 studies identified in this paper have a sample size of greater than 50 participants. When considering that the quality of evidence is low, and that 18 out of 46 studies failed to use a reliable or validated measure of self-reported pain and function clinicians must be wary when drawing conclusions based on study efficacy from this body of work.

CONCLUSION

Many different outcome measures have been used to assess pain and function in clinical trials that study the treatment of mid-portion AT with exercise rehabilitation. To assess pain and function the VISA-A appears to be the most valid and reliable tool. However, the NRS of pain during a functional task is possibly a simpler tool to assess immediate effect post-treatment or short-term effects of interventions as it may be more responsive to change. It is important for clinicians and researchers to be aware of the outcome measures that have been used as well as the reliability and validity of these measures. By identifying the best measures, rehabilitation professionals can optimize clinical assessment and improve clinical trials, as well as identify areas that require further research.

REFERENCES


33. Maffulli N, Walley G, Sayana MK, et al. Eccentric calf muscle training in athletic patients with Achilles...


## Appendix A. Individual Study Characteristics

<table>
<thead>
<tr>
<th>Study Name</th>
<th>Study Design</th>
<th>Cohort Size (n)</th>
<th>Loading Intervention in Exercise Arm of Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfredson et al. (1998)</td>
<td>Cohort</td>
<td>15</td>
<td>Heavy Eccentric Calf Training</td>
</tr>
<tr>
<td>Bell et al. (2013)</td>
<td>RCT</td>
<td>27</td>
<td>Heavy Eccentric Calf Training</td>
</tr>
<tr>
<td>Brown et al. (2006)</td>
<td>RCT</td>
<td>18</td>
<td>Heavy Eccentric Calf Training</td>
</tr>
<tr>
<td>Chester et al. (2008)</td>
<td>RCT</td>
<td>8</td>
<td>Heavy Eccentric Calf Training</td>
</tr>
<tr>
<td>Crill et al. (2014)</td>
<td>Cohort</td>
<td>25</td>
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<td>De Jonge et al. (2010)</td>
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<tr>
<td>De Jonge et al. (2011)</td>
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</tr>
<tr>
<td>De Jonge et al. (2015)</td>
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<td>54</td>
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<td>De Vos et al. (2007)*</td>
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</tr>
<tr>
<td>De Vos et al. (2011)</td>
<td>RCT</td>
<td>27</td>
<td>Heavy Eccentric Calf Training</td>
</tr>
<tr>
<td>De Vos et al. (2012)**</td>
<td>Cohort</td>
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<td>Heavy Eccentric Calf Training</td>
</tr>
<tr>
<td>Gardin et al. (2010)**</td>
<td>Cohort</td>
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<td>Herrington et al. (2007)**</td>
<td>RCT</td>
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<td>Horstmann et al. (2013)**</td>
<td>RCT</td>
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<td>Kearney et al. (2013)</td>
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<td>Knobloch et al. (2008)</td>
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<td>Langberg et al. (2007)**</td>
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<td>Maffuli et al. (2008)**</td>
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<td>Mafi et al. (2001)**</td>
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<td>Munteneau et al. (2015)**</td>
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<td>Norregaard et al. (2007)**</td>
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<td>Ohberg &amp; Alfredson (2004)**</td>
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<tr>
<td>Ohberg et al. (2004)**</td>
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<td>18</td>
<td>Heavy Eccentric Calf Training</td>
</tr>
<tr>
<td>Petterson et al. (2007)**</td>
<td>RCT</td>
<td>37</td>
<td>Modified Heavy Eccentric Calf Training</td>
</tr>
<tr>
<td>Rompe et al. (2007)**</td>
<td>RCT</td>
<td>23</td>
<td>Heavy Eccentric Calf Training</td>
</tr>
<tr>
<td>Rompe et al. (2009)**</td>
<td>RCT</td>
<td>30</td>
<td>Heavy Eccentric Calf Training</td>
</tr>
<tr>
<td>Roos et al. (2004)**</td>
<td>RCT</td>
<td>16</td>
<td>Modified Heavy Eccentric Calf Training</td>
</tr>
<tr>
<td>Sayana &amp; Maffuli (2007)**</td>
<td>Cohort</td>
<td>34</td>
<td>Heavy Eccentric Calf Training</td>
</tr>
<tr>
<td>Shalabi et al. (2004)**</td>
<td>Cohort</td>
<td>25</td>
<td>Heavy Eccentric Calf Training</td>
</tr>
<tr>
<td>Silbernagel et al. (2001)**</td>
<td>RCT</td>
<td>22</td>
<td>Eccentric Overload</td>
</tr>
<tr>
<td>Silbernagel et al. (2007)**</td>
<td>RCT</td>
<td>26</td>
<td>Eccentric Overload with Active Rest</td>
</tr>
<tr>
<td>Silbernagel et al. (2011)**</td>
<td>Cohort</td>
<td>34</td>
<td>Eccentric Overload</td>
</tr>
<tr>
<td>Stasinopoulos &amp; Manias (2013)**</td>
<td>RCT</td>
<td>20</td>
<td>Heavy Eccentric Calf Training</td>
</tr>
<tr>
<td>Stergioulas et al. (2008)**</td>
<td>RCT</td>
<td>20</td>
<td>Heavy Eccentric Calf Training</td>
</tr>
<tr>
<td>Stevens &amp; Tan (2014)**</td>
<td>RCT</td>
<td>14</td>
<td>Heavy Eccentric Calf Training</td>
</tr>
<tr>
<td>Tumilty et al. (2008)**</td>
<td>RCT</td>
<td>10</td>
<td>Heavy Eccentric Calf Training</td>
</tr>
<tr>
<td>Tumilty et al. (2012)**</td>
<td>RCT</td>
<td>17</td>
<td>Heavy Eccentric Calf Training</td>
</tr>
<tr>
<td>Tumilty et al. (2016)**</td>
<td>RCT</td>
<td>13</td>
<td>Heavy Eccentric Calf Training</td>
</tr>
<tr>
<td>Van der Plas et al. (2012)**</td>
<td>Cohort</td>
<td>46</td>
<td>Heavy Eccentric Calf Training</td>
</tr>
<tr>
<td>Yelland et al. (2011)**</td>
<td>RCT</td>
<td>15</td>
<td>Heavy Eccentric Calf Training</td>
</tr>
<tr>
<td>Yu et al. (2013)**</td>
<td>RCT</td>
<td>16</td>
<td>Heavy Eccentric Calf Training</td>
</tr>
</tbody>
</table>

*The results of this study are a follow up of an included study or present different components of data from another included study.
ABSTRACT

The anterior cruciate ligament (ACL) is the most commonly reconstructed ligament of the knee. Most often, the goal of surgical reconstruction is to recreate stability within the knee and prevent joint degeneration. To date, clinical studies have not demonstrated the ability of various reconstruction techniques in establishing complete knee stability when comparing rates of osteoarthritis. Rates of osteoarthritis commonly resemble those of knees which have not be reconstructed and in this light, may not demonstrate a successful outcome. As modern medicine continues to develop and in the understanding of underlying biological processes grows, some surgeons have turned their attention back to an ACL repair technique. The purpose of this clinical commentary is to discuss the parameters associated with a phase progression for an isolated ACL repair. Physiological healing time frames, along with objective clinical assessment, following a criterion-based progression is described in accordance with post-operative healing parameters to serve as a reference for a rehabilitation specialist.

Level of evidence: 5

Key words: Anterior cruciate ligament, periodization, rehabilitation, repair, return to sport
INTRODUCTION
Isolated anterior cruciate ligament (ACL) tears have been reported to occur at a rate of 68.8 per 100,000 people in the United States. Prior to 1970, many ACL tears were managed using an ACL repair procedure in order to recreate stability in the knee. These procedures were open surgical repairs and included all tear types, tear locations, patient ages and activity levels, and included various co-morbid knee injuries. Moreover, following the open ACL repair procedure the post-operative management regime usually included long leg casting in slight flexion for as long as six weeks. This management of ACL injuries resulted in poor patient reported outcomes and high failure rates ranging from 10% to as high as 100%, and consequently lead to surgeons abandoning ACL repairs in favor of ACL reconstructions.

The purpose of the ACL reconstruction is to create rotational and posterior/anterior knee stability, allowing the patient to resume their prior levels of activity while decreasing the chance of articular cartilage degeneration. When measured against these goals, ACL reconstructions are not always successful. Rates of degeneration and osteoarthritis do not appear to be slowed following ACL reconstruction with osteoarthritis development reported from 10% to as high as 100%; a rate similar to patients managed conservatively. Furthermore, despite efforts and intentions directed at returning patients to their prior level of activity participation, reconstruction of the ACL does not guarantee return to pre-injury status with just 65% of athletes returning to their prior functional level.

Given that positive outcomes after ACL reconstruction are not always certain, it seems appropriate to revisit ACL repairs. There are several potential benefits of repairing the ACL, including the avoidance of drilling tibial and femoral bone tunnels, which creates trauma to the knee joint. Tibial tunnel reaming during anatomic single bundle ACL reconstruction impacts the anterolateral meniscal root attachment, ultimately reducing failure strength. Furthermore, preserving the native ACL results in more consistent anatomical tissue placement when compared to ACL reconstruction with an additional benefit of maintaining vascular and proprioceptive structures considered vital in knee and lower extremity function and stability. Lastly, donor site morbidity is eliminated.

Seemingly, most opponents to the ACL repair point to the decreased ability for the ACL to heal, however, recent research supports the concept that the ACL does have some intrinsic capacity to heal. The proximal 1/3 of the ACL has been shown to have intrinsic healing properties that are similar to the medial collateral ligament (MCL) forming type III collagen fibers of similar histological make-up. The ability of the ACL to spontaneously heal would indicate that proximal ACL tears, when managed with an ACL repair may have the ability to restore joint stability. Many of the same healing properties proposed by the ACL repair are realized in the healing response procedure. Creating a healing stimulus by microfracturing around the anatomical footprint permits access to mesenchymal cells and a healing environment is established to support the ACL. In an attempt to aid the healing response, the addition of a suture fixation and a biodegradable screw could further secure the native ACL tissue to its origin. These factors, along with developments in surgical procedures and collagen-platelet-rich plasma scaffolding are allowing a second look at less invasive ACL surgeries.

POSTOPERATIVE REHABILITATION
The current literature relating to a criterion based rehabilitation protocol after an ACL reconstruction is inconsistent. Despite the high prevalence of ACL reconstruction in the literature, consensus regarding weight bearing, range of motion, and initiation and progression of a periodized strength training program including running and return to sport does not exist. The ACL repair, which is documented less
frequently in the current literature compared to the reconstruction, has even less support in the literature. With this in mind, concepts proposed in this commentary aim to blend a criterion-based progression with patient presentation and the appropriate timelines associated with tissue healing and muscle adaptation.

**Phase 1: Protection/ROM/Muscle Initiation (0-6 weeks)**

The goals outlined in Phase I are important in directing the patients’ overall return to function. The aim of the protection phase is not only to protect the repaired ACL, but to prepare the patient for the next phase of rehabilitation by restoring tibiofemoral and patellofemoral range of motion, initiating quadriceps activation, and resolving joint effusion.

Post-operative restrictions are put in place to provide protection to the repaired ligament. The patient is placed in a standard postoperative hinged-knee which is set to allow for 0° – 90° of knee extension and flexion during gait activities for six weeks. Further, patients are allowed to ambulate in partial weight bearing (PWB) with a gradual increase to full weight bearing occurring at two weeks following surgery. Crutches can be discontinued when the patient no longer demonstrates an antalgic gait or an extension lag during a straight leg raise.

The role of early range of motion after surgery in reducing post-surgical complications and improving outcomes has been established in the literature. Since passive tibiofemoral flexion and extension does not place undue stress on the surgically repaired ligament, no restrictions are placed on passive range of motion post surgically. Passive tibiofemoral flexion is achieved with passive edge of table flexion and wall-slides. Progression of range of motion is guided by subjective patient reports, and limitations into progressing range of motion are directed by patient reports of pain. When >110° of passive flexion is present, the patient is able to progress to stationary cycling without resistance as a way to assist with effusion. Passive tibiofemoral extension can be achieved with posteriorly directed femoral glides in relation to a fixed tibia. In conjunction with a posterior femoral glide, a rotary mobilization of the femur directed externally in relation to the tibia can assist with tibiofemoral extension.

Establishing full passive patellofemoral motion is also important in the protective phase. Adhesions that form in the gutters of the anterior knee and in the anterior interval can limit tibiofemoral and patellofemoral range of motion and increase joint contact pressures. As indicated by previous authors, patellar mobilizations in a superior/inferior and medial/lateral fashion should also be accompanied by medial/lateral mobilizations of both the patellar and quadriceps tendons to limit potential restrictions in both the tibiofemoral and patellofemoral joint.

Effusion in the tibiofemoral and patellofemoral joints can result in increased pain, decreased quadriceps activation, limited range of motion, and prevent the patient from progressing forward with rehabilitation. In accordance with physiological healing factors, joint effusion is expected to peak at day three and gradually resolve by the completion of Phase I at six weeks. Treatment to aide in the resolution of joint effusion may include lymphedema massage, the use of pneumatic compressive devices, elevation, and an active muscle pump from the quadriceps and calves. In addition to techniques aimed to decrease joint effusion, the rehabilitative specialist is encouraged to progressively stress the tissue within its tolerance to avoid increased joint effusion.

Quadriceps atrophy is common in an acute surgical knee and can lead to difficulty with active terminal knee extension during gait activities. Quadriceps training is initiated immediately after surgery with isometric quadriceps sets in terminal extension. As tolerated, quadriceps strengthening is progressed to short-arc, open-kinetic-chain strengthening from 30° to physiological terminal extension to aid with normal restoration of gait mechanics. The short-arc quadriceps exercise is shown to activate all quadriceps muscles at a greater EMG level as extension increases and have similar strain on the ACL compared to a closed-kinetic-chain squatting exercise.

Criteria for the progression from Phase I center around the goals outlined in Table 1. Initial passive range of motion into flexion and extension is performed by the therapist and should be maintained. Flexion is expected to be within 10° of the opposite limb, with efforts made to restore extension to values comparable to the contra-lateral limb. Finally, swelling is expected to be within 0.5 cm of the opposite
limb by the end of Phase I. Tables 2 and 3 provide examples of interventions commonly used at both weeks one and six.

**Phase 2: Periodized Strength Development**  
**Muscular Endurance (7–14 weeks)**

After completion of the protection phase, the focus turns to progressive loading of the knee joint and soft tissues through a periodized program that focuses on the sequential development of muscular endurance, strength and power. Due to arthrogenic inhibition, the selective atrophy of type 1 muscle fibers following injury provides the physiological rationale for the development of a muscular endurance base.20,33,34

Due to their decreased recruitment threshold requirements, type 1 muscle fibers are recruited and developed with light intensity and high repetitions.35

The strengthening of major muscle groups, especially the quadriceps, as outlined in Table 4 is recommended in Phase II. The rehabilitative specialist is encouraged to use this as a guide while working on an individualized treatment plan specific to the goals of each patient. An endurance based strength training program is recommended between two to

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**Table 1. Protection Phase Guidelines and Goals 0–6 weeks post-operative.**

<table>
<thead>
<tr>
<th>Precautions</th>
<th>Goals / Criteria to advance</th>
<th>Interventions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full ROM</td>
<td>Active terminal knee extension &gt;= 0</td>
<td>Passive tibiofemoral mobilizations (posterior femoral glides, screw home mobilizations)</td>
</tr>
<tr>
<td></td>
<td>Active flexion to within 10° of opposite knee</td>
<td>Passive patellofemoral mobilizations (superior/inferior, medial/lateral)</td>
</tr>
<tr>
<td></td>
<td>Patellar tendon and quadriceps tendon mobilizations (medial/lateral)</td>
<td>Manual soft tissue massage (quadiceps, hamstrings, gluteus medius/minimus, gastrocnemius/soleus)</td>
</tr>
<tr>
<td></td>
<td>Isometric quadriceps activation in terminal extension (building to 5 sets of 1 minute hold)</td>
<td></td>
</tr>
<tr>
<td>PWB</td>
<td>Gait without assistive device</td>
<td>Weight bearing progression (medial/lateral weight shifts, posterior/anterior weight shifts)</td>
</tr>
<tr>
<td></td>
<td>Swelling within 0.5 cm of opposite knee (measured at superior pole of patella, 5 cm and 10 cm proximal to superior pole of patella)</td>
<td>Weaning off assistive device (gradual removal of crutches)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reciprocating stair ascension/descent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bike (115° flexion present)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lymphedema massage, distal to proximal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ankle pumps (3 sets of 20 reps, 2–3 times / day)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Progression from mat muscle activation exercises to upright muscle activation exercises</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Balance progression (interventions include but are not limited to tandem stance, rhomberg stance, single leg stance, unstable surfaces, eyes opened/eyes closed)</td>
</tr>
</tbody>
</table>

ROM= range of motion. PWB= partial weight bearing.

---

**Table 2. Example of first week post-operative interventions.**

<table>
<thead>
<tr>
<th>Rehabilitation component</th>
<th>Intervention</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patellar mobility</td>
<td>Superior/inferior patella, quadriceps tendon, and patella tendon</td>
<td>10 minutes</td>
</tr>
<tr>
<td></td>
<td>Medial/lateral patella mobilization</td>
<td></td>
</tr>
<tr>
<td>Tibiofemoral Extension</td>
<td>Posterior capsule stretch</td>
<td>5-10 minutes</td>
</tr>
<tr>
<td></td>
<td>Screw home mobilization / posterior femoral glide</td>
<td></td>
</tr>
<tr>
<td>Tibiofemoral Flexion</td>
<td>Edge of table</td>
<td>10-15 minutes</td>
</tr>
<tr>
<td></td>
<td>Supine on ball</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wall slide</td>
<td></td>
</tr>
<tr>
<td>Knee, hip, and core strengthening</td>
<td>Quad sets-biofeedback (for 1 min)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Glute sets – (3 sets of 10-20 sec isometric hold)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TA sets – (3 sets of 10-20 sec isometric hold)</td>
<td></td>
</tr>
<tr>
<td>Edema management/ Soft tissue massage</td>
<td>Quad/knee</td>
<td>10-20 minutes</td>
</tr>
<tr>
<td></td>
<td>Hamstring</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Calf</td>
<td></td>
</tr>
<tr>
<td>Gait training PWB (two crutches)</td>
<td>Stationary upright bike (no resistance)</td>
<td>5-10 minutes</td>
</tr>
<tr>
<td></td>
<td>Ascending/descending stairs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TKE focus</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heel strike</td>
<td></td>
</tr>
</tbody>
</table>

PWB= partial weight bearing. TA = transversus abdominis. TKE= terminal knee extension.

The above mentioned interventions are appropriate during Phase I of rehabilitation and can be used and should serve as a guideline for clinicians between the first and sixth weeks of rehabilitation if determined appropriate by the clinician.
The single leg squat and the Y-Balance Test are used as indicators of surgical limb strength and stability. A single leg squat from a 10-inch step over 15 repetitions will allow the rehabilitation expert the opportunities to assess frontal plane kinematics and strength at the trunk, hips, and knees visually. Anterior reach on the Y-Balance Test has been correlated with knee injuries and return to sport in the literature, and is being used as a progressive objective measure to show strength in the surgically repaired leg.40-42

Despite the focus on the development of muscular endurance, lower extremity muscular strength is still three times each week with at least 48 hours of rest in between.35,36 Light to moderate loads of <50% of the patients’ 1-repetition maximum (1RM) are recommended for greater than 15 repetitions.36 ACSM guidelines encourage between two and four sets with rest periods <90 seconds.35,36 The progression of double to single leg activities is also recommended throughout the progression of this phase.

Phase II progression criteria are outlined in Table 5. Single leg strength has been shown as an important predictor for control of frontal plain kinematics37 and with return to sport decisions.10,11,38,39 Therefore, the

<table>
<thead>
<tr>
<th>Rehabilitation Component</th>
<th>Intervention</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patellar mobility</td>
<td>Superior/inferior patella, quadriceps tendon, and patella tendon mobilization</td>
<td>10 minutes</td>
</tr>
<tr>
<td>Tibiofemoral Extension</td>
<td>Posterior capsule stretch</td>
<td>5-10 minutes</td>
</tr>
<tr>
<td>(as needed)</td>
<td>Screw home mobilization / posterior femoral glide</td>
<td></td>
</tr>
<tr>
<td>Tibiofemoral Flexion</td>
<td>Edge of table with therapist assistance</td>
<td>10-15 minutes</td>
</tr>
<tr>
<td>(as needed)</td>
<td>Supine on ball with therapist assistance</td>
<td></td>
</tr>
<tr>
<td>Hip, knee, and core strengthening</td>
<td>Wall slide (supine on back) as previous</td>
<td></td>
</tr>
<tr>
<td>Edema management/Soft tissue mobilization</td>
<td>Standing heel raises</td>
<td>3 sets x 20 reps</td>
</tr>
<tr>
<td>(as needed)</td>
<td>4 way hip (standing or on table; flexion/adduction/adduction/extension)</td>
<td>3 sets x 15 reps (resistance)</td>
</tr>
<tr>
<td>Gait training (as needed)</td>
<td>Supine HS curl</td>
<td>3 sets x 15 reps (resistance)</td>
</tr>
<tr>
<td>Discharge assistive device</td>
<td>Balance (interventions include but are not limited to tandem stance, rhomboid stance, single leg stance, unstable surfaces, eyes opened/eyes closed)</td>
<td></td>
</tr>
<tr>
<td>HS= hamstring.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The above mentioned interventions are appropriate during Phase I of rehabilitation and can be used and should serve as a guideline for clinicians between the first and sixth weeks of rehabilitation if determined appropriate by the clinician.

<table>
<thead>
<tr>
<th>Exercise (Focus on exercise)</th>
<th>Repetitions / Sets</th>
<th>Work : Rest</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Wall squat holds (Quad)</td>
<td>30-120 sec / 2-4 sets</td>
<td>1:1, transition to none</td>
</tr>
<tr>
<td>a. TRX squats (Quad)</td>
<td>30-120 sec / 2-4 sets</td>
<td>1:1, transition to none</td>
</tr>
<tr>
<td>b. SL shuttle squats (Quad)</td>
<td>15-20 reps ea / 2-4 sets</td>
<td>1:1, transition to none</td>
</tr>
<tr>
<td>b. Supine bridge with HS curl (Hamstring)</td>
<td>15-20 reps / 2-4 sets</td>
<td>1:1, transition to none</td>
</tr>
<tr>
<td>c. Resisted lateral steps (Glutes)</td>
<td>15-20 reps ea / 2-4 sets</td>
<td>1:1, transition to none</td>
</tr>
<tr>
<td>c. Alternating lunge holds (Quad)</td>
<td>30 – 120 sec / 2-4 sets</td>
<td>1:1, transition to none</td>
</tr>
</tbody>
</table>

TRX= total body resistance exercise. SL= single leg. The above mentioned interventions are appropriate during Phase II of rehabilitation and can be used and should serve as a guideline for clinicians between the seventh and 14th weeks of rehabilitation if determined appropriate by the clinician.
muscular strength. A periodized model is used with the focus on muscle strengthening of the quadriceps. When compared to the muscular endurance phase, muscular strength development is characterized by an increase in load and reduction in repetitions. In addition to strength training, a running and agility progression are added with the goal of returning the athlete to practice by the completion of this phase. Development of muscular strength targets type II A and B muscle fibers. An example of possible exercise interventions is outlined in Table 6 with a continued focus directed towards quadriceps strengthening. A 10-repetition maximum is implemented to avoid overloading the joint and soft tissues. These values are also correlated with an equivalent load for measuring with a leg press machine in both single and double leg. A quadriceps symmetry index of 80% the non-surgical leg can also show strength progression.

Phase 3: Periodized Strength Development – Muscular strength (15 – 21 weeks)
After a muscular endurance base has been established, the focus of rehabilitation becomes regaining muscular strength. A periodized model is used with the focus on muscle strengthening of the quadriceps. When compared to the muscular endurance phase, muscular strength development is characterized by an increase in load and reduction in repetitions. In addition to strength training, a running and agility progression are added with the goal of returning the athlete to practice by the completion of this phase. Development of muscular strength targets type II A and B muscle fibers. An example of possible exercise interventions is outlined in Table 6 with a continued focus directed towards quadriceps strengthening. Similar to a Phase II, patients are expected to perform strength training interventions two to three times each week with at least 48 hours of rest between sessions. Moderate to heavy loads of at least 60-67% of a patient’s 1-RM are recommended for muscular strength development. Based off of a patient’s previous weightlifting experience, between 1 – 12 repetitions with two to six sets are used to help maximize

<table>
<thead>
<tr>
<th>Exercise (Focus of exercise)</th>
<th>Repetitions / Sets</th>
<th>Work : Rest</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Single leg squat to target (Quads)</td>
<td>30-120 sec ea / 3-5 sets</td>
<td>1:2-3 after complete round</td>
</tr>
<tr>
<td>a. Front squats with DB/KB (Quads)</td>
<td>6-8 reps / 3-5 sets 70-80%</td>
<td>1:2-3 after complete round</td>
</tr>
<tr>
<td>b. Weighted reverse lunges (Quads)</td>
<td>6-8 reps ea / 3-5 sets 60-80%</td>
<td></td>
</tr>
<tr>
<td>b. Nordic HS curl (Hamstrings)</td>
<td>8-15 reps / 3-5 sets</td>
<td></td>
</tr>
<tr>
<td>c. SL Skaters 3 way (Glutes)</td>
<td>30-120 sec ea / 3-5 sets</td>
<td>1:2-3 after complete round</td>
</tr>
<tr>
<td>c. B shuttle jumps (Quads)</td>
<td>30 -120 sec / 3-5 sets</td>
<td></td>
</tr>
</tbody>
</table>

Dynamic warm up (progress in intensity): High knees, butt kickers, A-skip, fwd/bwd lunge, Open/close gate, lateral shuffle, Over/under sideways, back pedal, sprint progression, ladders

DB= dumbbell. KB= kettlebell. HS= hamstrings. SL= single leg. B= bilateral.

The above mentioned interventions are appropriate during Phase III of rehabilitation and can be used and should serve as a guideline for clinicians between the 15th and 21st weeks of rehabilitation if determined appropriate by the clinician.
strength gains.\textsuperscript{36,49} Depending on the complexity of movement, rest times between two to five minutes are encouraged.\textsuperscript{38,49} It is also recommended that every four weeks, the patient goes through a de-loading week to allow for appropriate recovery of muscles and soft tissue structures with a resistance of 50-60% utilized.\textsuperscript{49}

To this point, a running progression has not been implemented and should only be included if the patients desired activities include running. A criterion based model that addresses strength\textsuperscript{50} in a dynamic and fatigued state\textsuperscript{51} is appropriate in determining a progression to running.\textsuperscript{52} A quadriceps index of 90% in ACL reconstructed knees has been correlated with near normal jogging mechanics and is considered an appropriate marker for assessing strength.\textsuperscript{53} Despite not being a validated criterion for the knee, these authors believe that a passing score during the Vail Sports Test allows a rehabilitation specialist to observe how a patient would accept load while in a fatigued state and provides insight to how they would perform during a running activity. With these criteria met and a satisfactory muscular strength base established, a staged running progression starting with 70% weight bearing is implemented in an Alter-G treadmill. A similar reduced load running progression can be completed in a pool initially at chest depth with progression to shallower water depths. Over the course of two to three weeks, weight bearing is progressed during each running session by 5% until able to tolerate 100% weight bearing. Table 7 gives an example of this progression, but clinical judgment should be used in the progression to minimizing swelling and pain. If significant swelling and pain present, the patient is to regress back to the previous day. When the patient is able to successfully run pain free for 20 consecutive minutes, and strength and endurance criterion are still met, a graded agility progression is started. Agility drills are added in a single plane and progressed from 25% of maximal speed. Despite a lack of concise evidence in the literature, these authors believe that after two successful consecutive sessions without swelling and pain, it is appropriate to increase the intensity of the agility drills by 25% of an athlete's subjective perception of intensity via rate of perceived exertion. In addition to increased intensity, the athlete and rehabilitation specialist begins to introduce planes of motion to the agility drills to prepare for return to sport.

Criteria for the advancement from Phase III are outlined in Table 8. As the patient progresses towards a return to activity, the use of objective measures defined by the literature are used to assess function. The progression of muscular strength continues to build on strength gained from the previous phase. Single limb strength is again assessed with the Y-Balance Test, however, the 4 cm difference from non-surgical leg now reflects data supported in the literature pertaining to decreased rates of injury.\textsuperscript{40-42} Back squat/leg press strength is expected to be at 80% of predicted 10 RM by the completion of phase III. The quadriceps symmetry index and girth measurements have been used in the past to assess return to sport and are expected to be at 90% and within 1 cm of non-surgical leg, respectfully.\textsuperscript{10} Another measure supported by the literature for return to sport is the hamstring/quadriceps ratio which has been established at 60% and measured using hand-held dynamometry.\textsuperscript{54} Finally patients must pass the single leg drop test as measured by

![Table 7](image7.png)

![Table 8](image8.png)
an inertial measurement unit (IMU), further assessing neuromuscular control by way of tibial angular motion and indicating a patients’ ability to control dynamic movements at their limb. Neuromuscular is believed to be an important factor in a successful return to sport. Rehabilitation facilities will likely not possess a three-dimensional motion analysis system able to capture tibial motion and therefore can rely on an accurate but more portable IMU system. Once these criteria are met, the patient is able to return to practice and progress to Phase IV.

**Phase 4: Periodized Strength Development – Muscular Power/Speed/Agility phase (22+ weeks)**

Historically, clearance for complete return to sport followed a time based model and was subject to clinical examination performed by the intervening surgeon occurring at six months. However with the primary factor for return to sport being time and with re-tear rates occurring at similar rates before and after six months from surgery, a stronger focus on a criterion based model, especially during this return to sport phase, should be used.

The fourth phase of rehabilitation is directed towards the development of muscular power, speed, and agility with the end goal being the complete return to sport. Continuing with a linear periodization model, appropriate strengthening, conditioning, power, speed, and agility drills that best replicate the demands of the sport or activity are incorporated.

As different sporting activities require various combinations of power, speed, and agility, it is up to the rehabilitative specialist to implement their knowledge of strength and conditioning to adequately prepare each athlete. An example of possible exercise interventions is outlined in Table 9 with the focus switching from strictly strength, to power and strength maintenance. Optimal power development uses a resistance of 30% of the patients 1-RM and is suggested to enhance athletic performance and thought to best simulate most athletic events. However, increasing both movement speeds and rate of force development, is best trained with 75-90% of the patients’ 1-RM for 1-5 repetitions. This is completed over three to five sets with two to five minutes of rest. The development of optimal power, speed, and agility can be targeted with intense, brief activities avoiding fatigue, and should be performed early in the session.

Table 10 outlines the goals for Phase IV. Strengthening should continue throughout this phase with a 10-repetition squat or leg press of 90% or greater being expected by the completion of the phase. Also, in accordance with strength, the patient must maintain

---

**Table 9. Example of Muscular Power Phase Interventions at Weeks 22+.
**

<table>
<thead>
<tr>
<th>Exercise (focus of exercise)</th>
<th>Repetitions / Sets</th>
<th>Work : Rest</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Power Clean (Power)</td>
<td>1-5 reps / 3-5 sets 70-90%</td>
<td>2-5 minutes</td>
</tr>
<tr>
<td>b. Front Squat (Strength)</td>
<td>6-10 reps / 3-5 sets 50-65%</td>
<td>1:3</td>
</tr>
<tr>
<td>c. Nordic Hamstring Curls (Strength)</td>
<td>12-20 reps / 3-5 sets</td>
<td>1:2</td>
</tr>
<tr>
<td>d. Conditioning (Endurance)</td>
<td>21 – 15 – 9 (repetitions performed of each movement per round)</td>
<td>None</td>
</tr>
<tr>
<td>- Burpees</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Box jumps</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Core Strengthening**

- Abdominal crunch Isometric hold 45 sec / 4 sets
- Prone back extension Isometric hold 45 sec / 4 sets

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**Table 10. Periodized Strength Development – Muscular Power/Speed/Agility Phase Guidelines 22+ weeks.
**

<table>
<thead>
<tr>
<th>Goals / Criteria to advance</th>
<th>Stipulations</th>
</tr>
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<tbody>
<tr>
<td>Modified T-test within norms of sports</td>
<td>Refer to normative values based on sports/position if appropriate</td>
</tr>
<tr>
<td>Single leg hop series</td>
<td>&gt;90% non-involved leg</td>
</tr>
<tr>
<td>10 rep squat / 10 rep leg press &gt;90%</td>
<td>Refer to appendix 1</td>
</tr>
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</table>
previously outlined values pertaining to anterior reach on the Y-Balance Test, quadriceps girth, quadriceps index, the Vail Sports Test, single leg hop/box drop with an IMU and hamstring / quadriceps ratio in order to return to unrestricted sport activity. Finally, the addition of the modified T-test and single leg hop series adds in the patients' ability to tolerate the rigors of the sport or activity and indicate they are able to return to unrestricted sports participation.46,52,57 Ultimately, the patient, doctor, and therapist should agree on the patients' ability to return to activity based on subjective and objective measures.

Limitations with this criterion driven progression include the lack of data supporting improved functional outcomes. Furthermore, because long-term studies utilizing current ACL repair techniques are lacking, clinicians must rely on data from reconstruction procedures along with physiological healing timelines to support our approach for the design of the optimal post-operative physical therapy program for patients following ACL preservation and repair. The concepts presented should continue to be challenged and progressed as new information is presented, but these concepts serve as a starting point for how best to approach the rehabilitation of the knee following repair of the ACL.

CONCLUSIONS
While there is limited research pertaining to post-operative rehabilitation for the ACL repair, this clinical commentary offers suggested interventions based on evidence from anatomical, biomechanical, tissue-healing studies, and current literature of ACL reconstruction in establishing a safe and structured postoperative protocol. With the possibility of more ACL repair procedures being performed, therapists may benefit from the suggested structured progression of rehabilitative criteria that are supported by literature to help improve patient outcomes. This commentary aims to serve as a framework for which future research in clinical and laboratory settings can build off of to further support the data presented.

REFERENCES


### Appendix 1. **Strength calculations**

#### Athletes Male

<table>
<thead>
<tr>
<th>Body Weight</th>
<th>80% 10 RM leg press (lbs) [Single leg]</th>
<th>90% 10 RM leg press (lbs) [Single leg]</th>
<th>10 RM leg press (lbs) [Single leg]</th>
<th>10 RM squat (lbs)</th>
</tr>
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<tbody>
<tr>
<td>100</td>
<td>250[138]</td>
<td>282[155]</td>
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#### Athletes Female

<table>
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<tr>
<th>Body Weight</th>
<th>80% 10 RM leg press (lbs) [Single leg]</th>
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<th>10 RM leg press (lbs) [Single leg]</th>
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#### General Population Male

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<th>10 RM leg press (lbs) [Single leg]</th>
<th>10 RM squat (lbs)</th>
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### Appendix 1. (continued) Strength calculations 43,44

<table>
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<tr>
<th>Body Weight (lbs)</th>
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<td>211[116]</td>
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</tbody>
</table>

* Squat / Leg press calculation notes and equations 43,44

- **Athletes**
  - Males are based off of 1.5 x body weight for 1 RM
  - Females are based off of 1.0 x body weight for 1 RM

- **General population**
  - Males are based off of 1.25 x body weight for 1 RM
  - Females are based off of 0.85 x body weight for 1 RM

- **1 RM back squat equation (based on weight and number or reps)**
  - 1 RM = rep weight x (reps)^0.1

- **10 RM from 1 RM**
  - Squat 1 RM = 10 RM x 100 / 75
  - Squat 10 RM = 1 RM x 75 / 100

- **Squat to leg press 10 RM conversion (convert to KGs)**
  - Leg press 10 RM = (Squat 10 RM/0.354) – 2.235
  - Squat 10 RM = (Leg press 10 RM x 0.354) + 2.235
ABSTRACT

Repetitive overhead throwing generates tremendous demands on the shoulder joint of the overhead athlete. Clinicians, therapists, and medical staff are charged with optimizing a throwing athlete's shoulder mobility and stability to maximize performance and prevent injury. Modifiable risk factors such as strength asymmetry, glenohumeral range of motion deficits, and scapulothoracic joint abnormalities contribute to the overhead athlete's predisposition to shoulder injury. Most shoulder injuries in the overhead thrower can be successfully treated nonoperatively to allow in-season return to sport. The optimal rehabilitation program must be based on an accurate evaluation of historical and physical information as well as diagnostic imaging. Return to play decisions should be individualized and should weigh subjective assessments along with objective measurements of range of motion, strength, and function. The purpose of this clinical commentary is to summarize the current literature regarding the nonoperative treatment options for these common injuries, and to present a treatment plan to safely return these athletes to the field of play.

Level of evidence: 5

Key words: Internal impingement syndrome, plyometric exercise, rehabilitation, shoulder, throwing shoulder

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BACKGROUND AND PURPOSE
Repetitive overhead throwing generates tremendous demands on the glenohumeral joint at extremely high angular velocities. Shoulder torque during pitching movements can result in moments in excess of 7500 degrees/sec.¹ These extreme stresses must be balanced by adequate stability in the shoulder girdle to allow an athlete to compete throughout the course of a season. Increased incidence of shoulder pathology has been well documented in overhead athletes as compared to non-throwing athletes.² Conte et al. reported that 28% of all injuries sustained to professional baseball pitchers occur within the shoulder.³ The most frequently encountered shoulder injuries relate to pathology of the rotator cuff, the biceps-labral complex, and the shoulder capsule.⁴ Most of these injuries can be treated nonoperatively, and an optimal rehabilitation protocol should seek to balance minimizing time lost to injury while preserving long-term healing and preventing reinjury or compensatory pathology. In professional athletics especially, successfully returning to sport participation while still in season can have enormous effects on player salaries, contracts, and organizational/team success. The purpose of this clinical commentary is to summarize the current literature regarding the nonoperative treatment options for these common injuries, and to present a treatment plan to safely return these athletes to the field of play.

PRINCIPLES OF TREATMENT
The optimal rehabilitation program must be based on findings from the medical history, physical examination, and diagnostic imaging when appropriate. Optimally, the medical professional should also evaluate the isokinetic profile and throwing mechanics to discern the cause of decreased performance and pain.⁵ To achieve this, Wilk et al. described the evaluation broken down into the osseous structures, capsular structures, and muscular structures of the shoulder joint complex.⁶ For example, there may be osseous adaptations (increased retroversion), posterior musculature tightness, posterior capsular tightness, and even altered scapular position. The complex interplay of these three elements in overhead throwing athletes can lead to motion adaptations that may differ from the normal population. Once the offending pathology is identified, the rehabilitation program must be multi-phased and sequential. Each phase becomes more aggressive and demanding, gradually re-introducing the functional demands of the overhead athlete’s sport requirements. A successful rehabilitation program focuses on intermuscular balance, strength, endurance, neuromuscular control, and dynamic stability. Furthermore, a successful program should include attention to all elements of the kinetic chain, from lower body and core strengthening to hip and knee range of motion (ROM).⁷ Successful return to sport relies upon completion of a comprehensive, supervised rehabilitation program with an emphasis on constant communication between the athlete, coaches, and clinicians. Return to play (RTP) decisions should be weighted heavily on subjective measures discerned from this communication, as well as objective measures of ROM, muscular strength, balance, and function.⁸ As always, individual clinical judgment and understanding of the athletic context (demands, time of season, etc.) are encouraged.

PHYSICAL EXAMINATION
A thorough physical examination is an essential component of the evaluation of the thrower’s shoulder. If a complete physical examination of the shoulder cannot be performed due to pain and inflammation associated with injury, the examination should be deferred until adequate control of pain and acute inflammation is achieved. Once pain has improved, a thorough physical examination should be conducted focusing on areas of tenderness, ROM deficits, and strength limitations.⁹ Further, the physician, physical therapist, or athletic trainer should look for concomitant pathologies and functional deficits in all segments of the kinetic chain.⁸

Nonoperative Rehabilitation
After a thorough history and physical examination are completed, rehabilitation programs should pay special attention to: (1) rotator cuff strength and endurance abnormalities (isolated and intermuscular balance), (2) correcting ROM deficits, (3) optimizing scapulothoracic joint stabilization and shoulder flexibility, and (4) progressively and systematically re-introducing functional sport-specific stresses on the overhead athlete.⁸ The four phases of nonoperative treatment will be addressed in the following pages, and are summarized in Table 1.
recruitment of rotator cuff muscles. Management of pain is necessary to obtain optimal performance in the throwing motion. During the initial stage of treatment, an athlete may be prescribed oral nonsteroidal anti-inflammatories drugs (NSAIDs) and/or corticosteroid injections.11 For the high-level throwing athlete, steroid injections have demonstrated greater improvement in shoulder function and decreased pain levels, without increased risk of complications at four to six weeks as compared to NSAIDS.12 Adjuvant treatments for pain relief can be accomplished using ice, low-level laser therapy,13 ultrasound, and iontophoresis,13,14 however the long-term efficacy of these modalities in the acute phase of rehabilitation has yet to be defined.6 There is Level-1 evidence supporting use of continuous cryotherapy as an adjunct to decrease inflammation by reducing intra-articular temperatures, however these studies were performed in the shoulders of patients who had undergone arthroscopic shoulder surgery.15,16 After resolution of acute inflammation, moist heat, warm whirlpool, and ultrasound can be used to increase local circulation and soft tissue extensibility of the shoulder joint.

Phase 1 - Acute Phase
The primary goal of Phase 1 is to address acute inflammation and pain if present. Once this is complete, stretching treatment for shoulder ROM deficits and scapulothoracic joint abnormalities (dyskinesia) can begin. Also, important at the early stages of rehabilitation is attention to the upstream components (legs, core, spine) of the kinetic chain. The key components of Phase 1 of rehabilitation will be outlined in this section.

PAIN/INFLAMMATION
Introduction of an acute subacromial pain stimulus demonstrated a 22.7% decreased infraspinatus electromyography (EMG) activity with a corresponding decrease in external rotation (ER) force of 32.8% in healthy patients.10 Stackhouse et al. found that experimental subacromial pain elicits a decline in force and activation of the infraspinatus.10 Although internal impingement is a much more common reason for pain compared to external (subacromial) impingement in the overhead throwing athlete, these findings suggest a relationship between pain and proper

<table>
<thead>
<tr>
<th>Phases</th>
<th>Benchmark – When to Begin</th>
<th>Goals</th>
</tr>
</thead>
</table>
| Phase 1 | Immediately after injury | 1. Address acute inflammation/pain  
2. Evaluate and normalize ROM deficits  
3. Impede muscle atrophy  
4. Restore proprioception  
5. Begin kinetic chain exercises |
| Phase 2 | Once pain and inflammation diminish, and neuromuscular control and static stability reach adequate levels | 1. Re-establish inter-muscular balance in glenohumeral and scapulothoracic joints  
2. Continue Phase 1 activities for range of motion, flexibility, and neuromuscular control  
3. Further kinetic chain program and start a conditioning program |
| Phase 3 | Athlete has achieved full active and passive ROM, at least 4/5 manual muscle test strength, minimal pain, and symmetrical capsular mobility | 1. Initiate aggressive strengthening drills  
2. Enhance power and endurance  
3. Begin athlete specific functional drills  
4. Initiate aggressive kinetic chain and conditioning programs |
| Phase 4 | The athlete completes satisfactory clinical examination; non-painful ROM; satisfactory isokinetic test results; appropriate rehabilitation progress; and completed a successful plyometric program | 1. Return functional sport and position specific demands on the athlete |

Table 1. Return to throwing (4 phases)

ROM - range of motion
complex. Functional stresses and strains placed on the shoulder must be minimized by decreasing sport-specific and non-sport specific workloads.

**GLENOHUMERAL INTERNAL ROTATION DEFICIT (GIRD) CORRECTION**

Normal internal range of motion in overhead throwing athletes averages anywhere from 36 to 62° in the dominant shoulder and from 42 to 71° in the non-throwing shoulder. Several studies have demonstrated that the dominant arm in throwing athletes, as compared to the non-dominant arm, has a significant decrease in internal rotation (IR) at the glenohumeral joint. One pathophysiological explanation for the decreased IR is that a compensatory increase in ER is believed to aid in creating maximum velocity during the pitching motion. The resultant increase in ER results in stretching of the anterior capsule and tightening of the posterior capsule, resulting in loss of IR. The significant loss of IR is referred to as glenohumeral internal rotation deficit (GIRD), and is defined as a loss of IR of the throwing shoulder compared to the contralateral non-injured shoulder, and generally is greater than 17°.

Patients without access to the tool depicted in Figure 1A (The Rotater, Joint Mechanix LLC, Salem, AL) or in cases where pain or provocation is caused by this stretch, may accomplish the same stretch using the sleeper stretch (Figure 1B).

Pathogenesis of posterior capsular contracture of the shoulder in the overhead athlete is associated with the follow-through motion in throwing. These repetitive forces on the posterior capsule are believed to cause capsular hypertrophy, which limits IR. Further, there is a strong association between GIRD and posterior capsule tightness in patients with internal impingement of the shoulder. If posterior capsular tightness is present, there is also evidence to support the use of sleeper stretches with joint mobilization.

The overall treatment of GIRD in Phase 1 includes examining the following deficits: decreased IR, increased ER, posterior muscle and capsular tightness, and determining osseous adaptations. This is followed by aggressive employment of active-assisted ROM, passive ROM, manual stretches, and mobilization techniques to normalize motion. In the author’s experience, acceptable levels of IR can be expected to be obtained within about two weeks.

**SCAPULAR FLEXIBILITY AND SOFT TISSUE MOBILIZATION**

Scapular dyskinesis, or abnormal scapular control due to imbalances of scapular musculature, is associated with shoulder pathology. It is of particular
Concern in the overhead athlete, as scapular dyskinesis was found to have a 28% greater reported prevalence in overhead athletes compared to non-overhead athletes. In overhead athletes, the scapula often appears protracted, depressed, and anteriorly tilted in relation to the contralateral scapula. An anteriorly tilted scapula with decreased upward rotation is strongly associated with a loss of IR. Proper scapular muscle balance and flexibility is important to couple movements into upward rotation, posterior tilting, and adequate internal or ER (depending on motion). This is important to avoid impingement and enhance proximal stability of the shoulder joint complex to allow for greater distal control, avoid instability, and thus prevent injury.

Management of the scapulothoracic joint focuses on restoring flexibility of musculature of the scapula, including the pectoralis minor, levator scapulae, rhomboids, and the posterior capsular structures. Range of motion of the scapulothoracic joint should be examined with scapular elevation–depression, upward–downward rotation, anterior–posterior tilting, protraction–retraction, and medial–lateral rotation. Evaluation of scapular muscles and pectoralis minor length should also be performed. Specific stretches for the pectoralis minor may be performed with the unilateral corner stretch, or alternatively with the assistance of a physical therapist/athletic trainer (Figure 2). Soft tissue mobilization techniques are also recommended to treat scapulothoracic pathology (Figure 3A-C).

Overall Phase 1 management of scapulothoracic pathology includes addressing the following: correcting posture, improving muscle strength of the lower and middle trapezius, serratus anterior, and managing soft tissue tightness or pain.

**IMPEDE MUSCLE ATROPHY**

Isometric exercises of the internal and external rotators of the shoulder should be initiated during phase
one to impede muscle atrophy, and improve proprioception and dynamic stabilization. Isotonic exercises can be started if there is minimal muscle soreness during phase 1 to impede muscle atrophy. However, if the athlete is extremely sore or painful, then submaximal isometric exercises are done instead, and later progressed to aggressive isotonic exercises during phase two. This requires a focus on improving the strength of the weak muscles, such as the external rotators and scapular retractor, protractor, and depressor muscles.

**PROPRIOCEPTION RESTORATION OF INVOLVED SHOULDER**

Neuromuscular feedback mechanisms, specifically proprioception, become interrupted secondary to trauma and microtrauma. The repetitive forces of the throwing motion predispose the overhead athlete to losses in proprioception. Proprioception is important in rehabilitation and restoration of pre-injury levels of performance for the overhead athlete as it allows for awareness of body position and movement to be performed without continuous reference to consciousness. This allows for a level of control which is necessary for later strengthening, performance, and a reduced chance of reinjury.

Proprioception of both the glenohumeral joint and scapular stabilizers are the focus of Phase 1 management. Agonist/antagonist muscle coactivation of the rotator cuff is emphasized through rhythmic stabilization exercises, and proprioceptive neuromuscular facilitation (PNF) patterns with rhythmic stabilization. For the scapular stabilizers, Mottram et al. described the “scapular orientation exercise”, which involves sustained holds of the scapula in ideal postural positions for 10 seconds, repeated 10 times.
**Kinetic Chain Deficit Evaluation and Early Exercise**

Early implementation of kinetic chain exercises helps prepare the body for later incorporation of intensive shoulder and full body exercises. Exercises should be designed with the movement of the overhead-throwing athlete in mind. Common potential deficits to examine include: (1) inflexibilities of the hamstrings, hip, and/or trunk, and (2) core musculature weakness. Lightweight isotonic exercises should be first attempted (e.g. side plank, gluteal bridge, and dynamic stability tasks in quadruped and prone using the arms and legs as levers). Kinetic chain exercises include core, lower body, and axial loading exercises, which are also beneficial in restoring proprioception. Gait and stance adaptations have been shown to exist in overhead throwing athletes with upper extremity injury as evaluated by the Y Balance Test. In theory, poor balance could negatively affect throwing mechanics and lead to injury. Fortunately, correction of upper extremity deficits has also shown to improve lower extremity balance.

**Phase 2 – Intermediate Phase**

Goals of Phase 2 are to begin isotonic strengthening activities focused on restoration of shoulder joint muscle balance if unable to do so in Phase 1, and to continue to increase flexibility, mobility, ROM and neuromuscular control of the shoulder complex. These strengthening activities should focus on correcting the individual pathology determined during Phase 1 evaluation. Continued exercises for the entire kinetic chain, and an introduction of shoulder endurance programs are recommended. Phase 2 can begin once pain and inflammation diminish, and neuromuscular control and static stability reach adequate levels (Table 2). The rehabilitation program for the overhead athlete must pay special attention to the strength, stability, and inter-muscular balance of the muscles of the rotator cuff and scapulothoracic joint.

**Glenohumeral joint musculature (rotator cuff muscles)**

Overhead athletes often exhibit sport-specific adaptations leading to a relative decrease in the strength of the external rotators and thus muscular imbalance in the rotator cuff. Eccentric muscle strength of the external rotators is very important in the deceleration of the arm, and weakness predisposes the athlete to increased destabilization of the humeral head in the glenoid fossa, and potential injury. Muscular balance goals for external and internal rotator strength are provided in Appendix A.

Exercises begin with light weight but should be gradually increased as tolerated. Wilk et al. used EMG research of numerous investigators to design the Thrower’s 10 Program, which attempts to address the vital muscles involved in the throwing motion. Exercises in the program used to address ER deficits include prone rowing into ER and side lying ER. Specifically, these exercises target the infraspinatus and teres minor muscles. For the supraspinatus, Reinold et al. reported that the best exercise was the “full

<table>
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<th>Table 2. Phase 1 – Acute phase</th>
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<tr>
<td><strong>Goal</strong></td>
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<td>1. Address acute inflammation/pain</td>
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<td>2. Evaluate and normalize ROM deficits</td>
</tr>
<tr>
<td>3. Impede muscle atrophy</td>
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<tr>
<td>4. Restore proprioception</td>
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<tr>
<td>5. Begin kinetic chain exercises</td>
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ROM – range of motion, NSAID – nonsteroidal anti-inflammatory drug, PNF - proprioceptive neuromuscular facilitation
can” exercise, or elevation in the scapular plane with full ER (thumb up). Boettcher et al. found that pendant ER and prone ER may maximize supraspinatus strengthening while minimizing deltoid activity. Malanga et al. found that selective isolation of the supraspinatus is difficult and that both prone exercises and exercises in the scapular plane result in recruitment of the posterior and anterior deltoid fibers, respectively.

**SCAPULAR STABILIZERS**
Peri-scapular muscles are extremely important in maintaining the proper position, and stability of the scapula at rest and during the throwing motion. Proper scapular function is also key in facilitating the transfer of energy from the main force generators of the kinetic chain – the legs and trunk – to the hand. Re-establishing inter-muscular balance of the scapular musculature is important in preventing injury as well as optimizing performance.

Exercises should target potential weakness in serratus anterior strength, hyperactivity and early activation of the upper trapezius, decreased activity and late activation of the lower trapezius, neuromuscular control, and synchronized movement. Kibler et al. identified specific exercises for scapular control including the low row, lawn mower (the arm is brought to the contralateral knee and retracted back through with full retraction of the scapula to the ipsilateral side and extension of the hips and trunk), and robbery (the trunk is flexed 40-50º with the arms forward flexed, then scapular retraction is performed, with elbows bent and arms externally rotated and held for five seconds while extending the hip and trunk) exercises. Wilk et al. developed specific exercise drills to enhance scapulothoracic neuromuscular control. For the serratus anterior, supine protractions and wall push-ups are recommended. To target middle and lower trapezius activation while minimizing upper trapezius activation, side lying ER, prone forward flexion, prone horizontal abduction with ER, and prone extension are recommended.

**CONTINUE ROM, FLEXIBILITY, AND IMPROVE NEUROMUSCULAR CONTROL**
Phase 1 stretches and exercises for ROM, flexibility, and neuromuscular control should be continued during this phase. To increase neuromuscular control, stabilization drills at end ROM, including PNF exercises performed in a full arc of patient's available ROM should be added.

**STRENGTHENING OF KINETIC CHAIN AND CONDITIONING**
Proper management of the kinetic chain in a rehabilitation program allows for efficient and consistent transfer of energy from proximal to distal components. This allows the overhead athlete to: (1) reduce kinetic stress on the shoulder to prevent injury, and (2) generate added force to increase maximum velocity and increase performance. For the overhead athlete, the activities of the shoulder work within a diagonal pattern kinetic chain, spanning from the ground through to the trunk. Exercises should be designed from diagonal patterns as this has shown to increase scapular muscle activity. In Phase 2, exercises should advance to isotonic strengthening of the lumbopelvic musculature (Table 3). A sport and position-specific cardiovascular conditioning program should begin during this phase.

**Phase 3 – Advanced Strengthening Phase**
Phase 3 can begin once the athlete has achieved full ROM, at least 4/5 manual muscle test strength, and minimal pain. The goals are to initiate progressive strengthening drills, enhance power and endurance, and perform functional drills (Table 4). In Phase 2, inter-muscular imbalances should have been corrected and more protective muscle balance should now be seen. The focus of Phase 3 is to actively advance strength and control during sport and position-specific movements through integration of the kinetic chain throughout the shoulder exercise program.

Phase 3 requires introduction of fatiguing activities for the shoulder joint complex and rest of the kinetic chain. A study examining EMG activity of the muscles of the rotator cuff and scapula during a diagonal movement task demonstrated that fatiguing protocols led to decreased lower trapezius activity and a compensatory increase in infraspinatus activity, predisposing the infraspinatus to injury during functional tasks. Fatigue has been associated with a decrease in neuromuscular control, and ball velocity, lead lower extremity knee flexion and shoulder adduction torque, and an increase in humeral head superior translation during the...
49 The introduction of sustained isometric holds has been shown to increase motor recruitment. Evidence supports that sustained isometric contractions can lead to increased muscular hypertrophy.63 These ideas led to the suggestion that incorporating sustained isometric holds, as done in the Advanced Thrower’s 10 Program, will increase muscle activation and lead to added muscular strength, endurance, and dynamic stabilization. Further, sustained contraction increases the demand on the shoulder, preparing the athlete for return to sport. In a recent randomized clinical trial, Myers et al. demonstrated improved upper extremity torque and angular impulse during scaption exercises after completing six-weeks of the Advanced Thrower’s 10 Program, though there were no significant differences compared to a traditional exercise program.

### SPORT-SPECIFIC ADVANCED STRENGTHENING

To maintain focus on the vital muscles of the throwing motion, and implement increasing sport-specific demands, Wilk et al. created the Advanced Thrower’s 10 Program, which adds alternating movement patterns, and alternating dynamic and sustained isometric sequencing.49 The introduction of sustained isometric holds has been shown to increase motor recruitment. Evidence supports that sustained isometric contractions can lead to increased muscular hypertrophy.63 These ideas led to the suggestion that incorporating sustained isometric holds, as done in the Advanced Thrower’s 10 Program, will increase muscle activation and lead to added muscular strength, endurance, and dynamic stabilization. Further, sustained contraction increases the demand on the shoulder, preparing the athlete for return to sport. In a recent randomized clinical trial, Myers et al. demonstrated improved upper extremity torque and angular impulse during scaption exercises after completing six-weeks of the Advanced Thrower’s 10 Program, though there were no significant differences compared to a traditional exercise program.

### Table 3. Phase 2 – Intermediate phase

<table>
<thead>
<tr>
<th>Goal</th>
<th>Treatment Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Re-establish inter-muscular balance in glenohumeral and scapulothoracic joints</td>
<td></td>
</tr>
<tr>
<td>2. Continue phase 1 activities for range of motion, flexibility, and neuromuscular control</td>
<td></td>
</tr>
<tr>
<td>3. Further kinetic chain program and start a conditioning program.</td>
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</tr>
</tbody>
</table>

1. Thrower’s 10 Program (prone rowing into ER, side lying ER, “full can” exercise) For scapulothoracic articulation employ low row, row with external rotation (“lawnmower”), and external rotation with abduction (“robbery” position) for scapular control; supine protraction and wall push-ups for serratus anterior strength; side lying ER, lying forward flexion, prone horizontal abduction with ER and prone extension for middle and lower trapezius

2. Phase 1 stretches and add on stabilization drills at end range of motion

3. Isotonic strengthening of lumbopelvic region and a sport and position specific conditioning program

ER – external rotation

### Table 4. Phase 3 – Advanced strengthening phase

<table>
<thead>
<tr>
<th>Goal</th>
<th>Treatment Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Initiate aggressive strengthening drills</td>
<td></td>
</tr>
<tr>
<td>2. Enhance power and endurance</td>
<td></td>
</tr>
<tr>
<td>3. Begin athlete specific functional drills</td>
<td></td>
</tr>
<tr>
<td>4. Initiate aggressive kinetic chain and conditioning programs</td>
<td></td>
</tr>
</tbody>
</table>

1. Advanced thrower’s 10 program

2. Plyometric exercise program (chest pass, overhead soccer throw, side-to-side throws, side throws); wall dribbling with playball, wall arm circles, underweight ball throws, and overweight ball throws

3. Manual resistance stabilization, dynamic stabilization, and rhythmic stabilization at maximal ER with added perturbations

4. Functional, aggressive lumbopelvic strengthening

ER – external rotation

All these factors contribute to diminished performance, and a greater likelihood of injury. Proprioception exercises that focus on strength, dynamic stability, and neuromuscular control exercises at end-range ER should also be introduced during Phase 3. Some examples of proprioceptive exercises which focus on axial loading include planks, shoulder ER in plank position, and hand on wall stabilization drills.6
PLYOMETRICS

Plyometric exercises have three stages: (1) high velocity eccentric contraction (pre-stretch), (2) storage of the elastic energy (amortization), and (3) release of the kinetic energy in a powerful concentric contraction. This type of exercise is believed to encourage neuromechanical adaptations to allow the muscle to tolerate a higher rate of pre-stretch and transition more quickly to concentric contractions. These adaptations to the muscle alter the kinematic risk factors for injury, while leading to added performance by increasing the transfer of energy from the lower extremities and trunk to the upper extremity.

Because of the added risk of injury found in weak eccentric activity of the rotator cuff musculature, plyometric exercises target eccentric contractions of the posterior musculature and are believed to provide added protective benefit to the overhead athlete. Wilk and colleagues established a plyometric exercise program for the overhead thrower. Some of these exercises include two-handed exercise drills like chest pass, overhead soccer throws, side-to-side throws, and side throws. A recent study demonstrated decreases in eccentric, amortization, and concentric phase times for both plyometric and strength training groups and increases in scapular upward rotation for both groups, providing objective evidence for the effectiveness of these strengthening exercises in producing upper extremity protective and performance benefits. Further, the addition of plyometrics demonstrated an increase in shoulder passive IR ROM. The shortened amortization phase is believed to increase power development by increasing stored elastic energy and subsequent kinetic energy released, and reduces shoulder injury by limiting the amount of time that the shoulder is in potentially harmful positions – abduction and maximum ER.

Fatigue is a major risk factor for injury in the overhead athlete. Studies have shown that muscle fatigue is the leading factor predisposing the Little League pitcher to shoulder injury while pitching. Additional non-plyometric exercises than can aid in improving endurance include exercise drills which include wall dribbling with a plyometric ball, wall arm circles, and underweighted and overweighted ball throws.

Increases in maximal ER are believed to have performance benefits in the form of increased velocity. In Phase 3, manual resistance stabilization, dynamic stabilization, and rhythmic stabilizations should continue to be performed, but now at maximal ER, and with added perturbations. Kinetic chain consideration focused on lower body, core, and axial loading exercises should continue to be prescribed as well. The conditioning program should be increased, with the continued understanding of fitness demands required for a particular position and sport in mind.

Phase 4 – Return to Throwing Phase

Phase 4, the interval-throwing program, is initiated once the athlete completes: (1) satisfactory clinical examination; (2) non-painful ROM; (3) satisfactory isokinetic test results if such testing is available; (4) appropriate rehabilitation progress; and (5) successful completion of a plyometric program. The interval-throwing program is broken into two stages, with strict adherence to proper throwing mechanics and fundamentals necessary to progress within each phase and between each phase (Table 5). Improper use of throwing mechanics or the kinetic chain may result in delays in recovery or re-injury. Through-out Phase 4, open communication is key to ensure that there is no pain or stiffness during the throwing

<table>
<thead>
<tr>
<th>Table 5. Phase 4 – Return to throwing phase</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Goal</strong></td>
</tr>
</tbody>
</table>
| Return functional and sport specific demands on the athlete | 1. Interval throwing program  
2. Stage 1 ➔ pre-mound throwing  
3. Stage 2 (pitchers) ➔ Mound throwing  
4. Stage 2 (position players) ➔ Distance throwing |
motion, and only minimal soreness exists after a throwing session. Any significant pain, or pain deep in the shoulder during the throwing motion warrants halting of all exercises for that day and reassessment on a later date for return to the throwing program.

During the throwing motion, proper employment of the kinetic chain in the form of a “gathering step” and conscious use of the legs and trunk should be enforced, especially early in the long-toss program.7 Throwing should be made “on a line” rather than in a “high arc”, and a four-seam fastball grip should be used. Care should be taken early on to ensure throws are made with submaximal effort.7,69 Although historically a long-toss program is implemented, a recent survey study has shown there is a high level of variability in parameters used in professional athletes for the long-toss program.70 Until completion of the program, throwing activities should be performed every other day, with successful completion of three throwing days warranting advance to the next level. Position considerations and an understanding of the context of the athlete’s season should be taken in the individual design of an athlete’s program.

See Table 6 for detailed stages of return to throwing.

**RETURN TO PLAY (RTP)**

Return to play (RTP) is an important decision for getting the athlete back to his/her sport. The decision should be made only after careful discussion between the physical therapist/athletic trainer, surgeon, and player. These decisions can be complicated by athlete and coaching preferences, as well as external pressures.71 Previous injury is associated with up to four-fold increase in re-injury.72 RTP decisions should always be individualized, and require substantial clinical judgment, though there has been a trend in the literature to try and standardize some of these decisions.71,73

Matheson et al. described the RTP model, which describes three steps that the clinician should take to systematically approach individual components and their sequence in RTP decisions.73 The first step is an evaluation of the athlete’s health status, which includes analytic and functional tests to determine medical factors. Appendix A outlines objective criteria to consider in assessing health status.8 The second step is a consideration of sport risk modifiers, with the goal of evaluating the athlete’s participation risk given the sport, position, and competitive level of the athlete. The third step involves a consideration of external modifiers, including social or economic pressures, and timing in the season. While this system helps to decrease controversy and provide a framework for consideration of all aspects of RTP, individual considerations and clinical judgment cannot be overemphasized in RTP decisions.

### CONCLUSIONS

This clinical commentary presents the current hypotheses on pathophysiology of throwing injuries that occur in the overhead athlete and provides evidence-based guidelines for conservative treatment. Rotator cuff muscular abnormalities, glenohumeral internal rotation deficits, and scapulothoracic joint

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**Table 6. Stages of return to throwing**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Initial objectives</th>
<th>Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1 – Pre-Mound Throwing</td>
<td>Day 1: 25 throws max at 20-45’</td>
<td>Long-toss program; progress distance 45, 60, 90, and 120’ 150’ goal for pitchers</td>
</tr>
<tr>
<td>Stage 2 (Pitchers) – Mound Throwing</td>
<td>Start at 45’ on mound; fastballs 50% max velocity; continue to increase number of pitches and distance</td>
<td>Modulating pitch velocity 75%-100%, breaking balls only once fastballs and changeups can be thrown</td>
</tr>
<tr>
<td>Stage 2 (Position Players) – Distance Throwing Phase</td>
<td>Focus on mechanics with progression to accuracy</td>
<td>Interval distance progression: 120, 150, 180’</td>
</tr>
<tr>
<td>Rest/Off-Day</td>
<td>Engage in activities similar in difficulty and intensity to exercises in phase 2</td>
<td>Keep shoulder loose, minimize soreness; 10-minute toss session</td>
</tr>
</tbody>
</table>
pathology contribute to the distinct shoulder complex pathologies seen in these athletes. A thorough history and physical examination are important for the rehabilitation specialist to accurately recognize the underlying cause of the pathology of an individual. The rehabilitation program should be multi-phased, and sequential, with a gradual reintroduction of sport-specific demands. RTP decisions should weigh subjective assessment as well as objective measures of ROM, strength, and function.

REFERENCES


Appendix A. Objective measures of ROM, muscular strength and balance, and function

<table>
<thead>
<tr>
<th>Structural Consideration</th>
<th>Criteria</th>
</tr>
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<tbody>
<tr>
<td>Glenohumeral Joint Range of Motion</td>
<td>IR ROM deficit of throwing arm &lt; 18° (for maximal protection)</td>
</tr>
<tr>
<td></td>
<td>NOTE: no consensus (values in the literature range from 18° to 25°)</td>
</tr>
<tr>
<td>Rotator Cuff Strength</td>
<td>1. Isokinetic ER/IR ratio of 66% or an isometric ER/IR ratio of 75–100%</td>
</tr>
<tr>
<td></td>
<td>2. General rotator cuff strength increase of 10% of the dominant throwing</td>
</tr>
<tr>
<td></td>
<td>side compared to the non-dominant side</td>
</tr>
<tr>
<td></td>
<td>3. Eccentric strength of the ER is equal to the isometric IR strength</td>
</tr>
<tr>
<td>Scapular Position and Muscle Strength</td>
<td>Position: 60° of upward rotation in full arm elevation</td>
</tr>
<tr>
<td></td>
<td>Strength: 10% increased strength of peri-scapular musculature on the</td>
</tr>
<tr>
<td></td>
<td>dominant side in one-handed sports</td>
</tr>
<tr>
<td>Pectoralis Minor Tightness</td>
<td>PMI* &gt; 7.65</td>
</tr>
</tbody>
</table>

IR – internal rotation, ER – external rotation, PMI - pectoralis minor length normalized based on body height.

*PMI is calculated by dividing the resting length of the muscle in centimeters by subject height in centimeters and multiplying by 100.

Appendix B. Physical examination

Subjective History
Observation/inspection

- Osseous structures (SC joint, AC joint, clavicle, acromion, coracoid, bicipital groove, scapula)
- Assess musculature: RC, deltoid, rhomboids, trapezius, serratus anterior, pectoralis minor

Range of Motion (Active and Passive)

- Glenohumeral motion
- Scapulothoracic motion
- Crepitus

Motor Strength

- Glenohumeral
- Scapular
- Arm/Forearm

Specific Maneuvers

- Impingement signs
  (Neer/Hawkins, cross-chest adduction, internal impingement)
- Stability Tests (Sulcus sign, relocation test, etc.)
- Special Tests, Biceps (Speed’s, Yergason’s)
- Special Tests, SLAP (Clunk, O’Brian’s active compression, Biceps load, Lemak, Pronated biceps load, etc.)

Neurologic Examination

Cervical Spine Examination

Performance Testing

- Isokinetic and motion analysis testing